DOT/FAA/TC-06/20

Federal Aviation Administration
Washington, DC 20590

Comparison of Human Ice Detection Capabilities and Ground Ice Detection System Performance under Post Deicing Conditions

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February 2006

U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-06/20		

4. Title and Subtitle	5. Report Date
Comparison of Human Ice Detection Capabilities and Ground Ice Detection System Performance under Post Deicing Conditions	February 2006
	6. Performing Organization Code ACB-330
7. Author(s) Kimberlea Bender, Edmundo A. Sierra, Jr., Scott M. Terrace, Isabelle Marcil, John D'Avirro, Edward Pugacz, Frank Eyre	8. Performing Organization Report No. DOT/FAA/TC-06/20
9. Performing Organization Name and Address Federal Aviation Administration, ACB 330 William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address FAA Office of Aviation Research, Flight Safety Branch Transport Canada, Transportation Development Centre	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Currently, after deicing operations, the presence of residual ice on an aircraft's wing is determined by a human deicer from a deicing ground crew via visual and tactile inspections. One method proposed to overcome some of the safety and physical concerns associated with human inspections is to use infrared camera based Ground Ice Detection Systems (GIDS). However, before regulatory authorities can consider GIDS for operational use, their performance had to be evaluated. In August 2005, the Federal Aviation Administration (FAA) William J. Hughes Technical Center's (WJHTC) Simulation and Analysis Group conducted a study sponsored by the FAA Office of Aviation Research, Flight Safety Branch (WJHTC), and Transport Canada's Transportation Development Centre to compare human ice detection performance using current visual and tactile techniques with the performance of two different GIDS under post deicing inspection scenarios. Nine male deicers from Globe Ground at Toronto Pearson Airport or Aero Mag 2000 Montreal performed post deicing inspections using three methods: the current method (visual inspections and tactile inspections), the GIDS1 method, and the GIDS2 method. Three separate post-deicing scenarios were presented each day for three days: a wing with 12 ice patches (High Contamination), three ice patches (Low Contamination), and a clean wing (No Contamination). Accuracy data, false detection data, and time to complete an inspection were collected and analyzed for each condition. The results from the study consistently indicated that overall GIDS1 was superior to human visual and tactile inspections and GIDS2 inspections in terms of accuracy, false detections, and stability in performance. Participants using GIDS1 were able to detect all patch sizes and thicknesses with the greatest accuracy while the other methods' accuracy improved as a function of patch size and thickness. In addition, inspections completed by the GIDS1 manufacturer throughout the study suggest that, with time and experience, performance could further improve.

17. Key Words	18. Distribution Statement
Deicing, ground icing, tactile inspections, visual inspections, GIDS, Ground Ice Detection Systems, human factors, engineering psychology, cold chamber, human capabilities, human limitations, aviation	This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	182	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgements

This report reflects the contribution of many individuals from various organizations whom the authors would like to acknowledge and thank for their efforts. Without them, this experiment would not have been a success.

We would like to thank Sherri Magyarits (FAA WJHTC, Simulation and Analysis Group) and Nicole S. Racine (Titan Corporation, Air Traffic Systems Division) for their assistance during the initial stages of the experiment.

Mario N. Rosa, Alexandre LeClair, and Jean-François Morin (Aero Mag 2000, Montreal) provided deicing expertise for icing scenarios and study design. They also served as participants during the pretest and provided participants for the study.

Darryl Golbeck, Kelvin Williamson, and Brad Beaver (Globe Ground) provided their expertise, participated in the pretest, and arranged participants for the study.

Nicoara Moc, Nicolas Blais, and Sami Chebil (APS) were responsible for creation of the ice samples and setting up the cold chamber.

We would also like to thank Christina Narlis (APS) for her help creating ice samples, reviewing and translating data collection materials, and for her assistance administrating the study.

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Executive Summary

Ice on an aircraft's wing poses a significant safety threat to flight operations. Currently, after deicing operations, the presence of residual ice on an aircraft's wing is determined by a human deicer from a deicing ground crew. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft. Tactile inspections expose extremities to cold surfaces, require close proximity to an aircraft (at times with engines on), are slow, and can be limited by the deicer's reach.

One method being proposed to eliminate post-deicing visual and tactile inspections is to use infrared camera based Ground Ice Detection Systems (GIDS). As GIDS are new technologies, many regulatory approval issues need to be addressed before these systems can be put into service. A GIDs Regulatory Approval Working Group (RAWG), under auspices of the SAE G-12 Ice Detection Sub-Committee, was formed to define the data and testing needed to provide regulatory authorities with the information they need to approve GIDS. To further this effort, in August 2005, Human Factor Specialists from the Federal Aviation Administration (FAA) William J. Hughes Technical Center's (WJHTC) Simulation and Analysis Group conducted a study sponsored by the FAA Office of Aviation Research, Flight Safety Branch (WJHTC), and Transport Canada's Transportation Development Centre. The objective of the study was to compare human ice detection performance using current visual and tactile techniques with GIDS performance under post deicing inspection scenarios. Two different GIDS were used for comparison; they were referred to as GIDS1 and GIDS2 throughout the study.

Nine male deicers from Globe Ground at Toronto Pearson Airport or Aero Mag 2000 Montreal performed post deicing inspections using three methods: the current method (visual inspections and tactile inspections), the GIDS1 method, and the GIDS2 method. All participants performed evaluations across each condition. Three separate post-deicing scenarios were presented each day for three days: a wing with 12 ice patches (High Contamination), three ice patches (Low Contamination), and a clean wing (No Contamination). Accuracy data (number of patches correctly detected), false detection data (number of patches identified that were not present), and time to complete an inspection were collected and analyzed for each condition.

The results from the study indicated that GIDS1 performed better than the current human detection system. The data gathered during the study consistently indicated that overall GIDS1 was superior to human visual and tactile inspections and GIDS2 inspections in terms of accuracy, false detections, and stability in performance. Participants using GIDS1 were able to detect all patch sizes and thicknesses with the greatest accuracy while the other methods' accuracy improved as a function of patch size and thickness. In addition, inspections completed by the GIDS1 manufacturer throughout the study suggest that, with time and experience, performance could further improve.

Acronyms

ANOVA	Analysis of Variance
FAA	Federal Aviation Administration
GIDS	Ground Ice Detection Systems
GOT	Grit Ordering Test
HF	Human Factors
M	Mean
Md	Median
MDA	MacDonald Dettwiler and Associates
OSHA	Occupational Safety and Health Administration
PTU	Pan Tilt Unit
RAWG	Regulatory Approval Working Group
SAE	Society Of Automotive Engineers
SD	Standard Deviation
SME	Subject Matter Expert
TA	Test Administrator
TC	Transport Canada
TLX	Task Load Index
WJHTC	William J. Hughes Technical Center

1. Introduction

Currently, after deicing operations, the presence of residual ice on an aircraft's wing is determined by a human deicer from a deicing ground crew. The presence of ice on a wing is determined visually under most circumstances. Tactile inspections may be required following deicing of certain types of "hard wing" aircraft, or for aircraft where cold soaked fuel may be a problem. Some problems have been identified with tactile inspections. Tactile inspections expose extremities to cold surfaces, require close proximity to an aircraft (at times with engines running), are slow, and can be limited by the deicer's reach.

To eliminate the safety and physical concerns of tactile inspections, the Federal Aviation Administration (FAA) and Transport Canada (TC) are exploring the potential to supplement or replace human visual and tactile inspections with remote Ground Ice Detection Systems (GIDS). Currently available, remote GIDS scan the wing surfaces of an aircraft and send pictures of potential ice contamination to a remote display that allows ground crews to evaluate whether or not ice is present. In this study, two different GIDS were used for evaluation: the Ice Camera by MacDonald Dettwiler and Associates (MDA) and the Goodrich IceHawk® by Goodrich Aerospace.

If visual and tactile inspections for the presence of ice on a wing are to be replaced with GIDS, these systems must be as good as, if not better, at detecting the presence of residual ice than human visual or tactile capabilities. A GIDS Regulatory Approval Working Group (RAWG), under the auspices of the SAE Committee G-12 Ice Detection Sub-committee, was formed to explore this possibility.

The GIDS RAWG is composed of representatives from the FAA, TC, end users, aircraft manufacturers, and GIDS manufacturers. The GIDS RAWG met at the William J. Hughes Technical Center (WJHTC) in Atlantic City, New Jersey in September 2004 to determine the most meaningful variables necessary to include in a study comparing current human visual and tactile inspections to a GIDS inspection. This report provides the details of the test designed to compare human performance with GIDS.

An initial experiment, hereafter referred to as the threshold study, was completed in March of 2005 (Sierra, Bender, Marcil, D'Avirro, Pugacz, & Eyre, in press). The threshold study attempted to quantify human visual and tactile ice detection capabilities to serve as a measure against which GIDS can be evaluated. Results from the threshold study were used to help determine the test parameters for this study. The research team attempted to address the limitations inherent in the threshold study, including the lack of movement in the visual study, reach limitations for tactile inspections, and the real-life stressors that exist in the field for current human methods (visual and tactile). The methodology of the current study was also consistent with the design of the threshold experiment where applicable. For example, environmental conditions in the chamber, instruments used to screen participants, and ice samples were determined in part by successful outcomes of the initial work.

2. Objective

The objective of the study was to compare human ice detection performance using current visual and tactile techniques with GIDS performance under post deicing inspection scenarios. The objective was accomplished by collecting ice detection data for both human deicers and GIDS inspections of wings similarly contaminated and comparing their detection performance.

3. Methodology

This study was comprised of three separate inspection scenarios: High Contamination, Low Contamination, and No Contamination performance tests. The High Contamination performance test was less realistic compared to real-world conditions in terms of the large number of ice patches on the wing, but was used to help alleviate the potential for ceiling effects (i.e. everyone performing flawlessly). The Low Contamination inspection scenario reflected a more typical post-deicing scenario to attempt to get a realistic measure of performance in the field. The No Contamination performance test was conducted to collect data on false positive identifications and to control learning effects. The only difference between the tests was the number of patches placed on the aircraft wing during trials.

The tests were conducted over three days, and therefore employed the same participants, study environment, ice sample characteristics, safety precautions, and operational procedures. The design and results of each test are discussed separately.

3.1 Participants

3.1.1 Deicers

This study employed nine participants from deicing ground crews. Participants, hereafter called deicers, were provided by Globe Ground at Toronto Pearson Airport and Aero Mag 2000 at Montreal Trudeau Airport. Participation in this study was strictly voluntary and no individual names or identities were recorded or released in any reports. We assigned each deicer a code (e.g., P1, P2, P3, etc.) that remained the same throughout the experiment; they will be referred to as such throughout this document. All parties maintained strict adherence to all federal and ethical guidelines throughout the study.

The deicers, ages 25 to 53, conducted inspections using current procedures and with GIDS during the three days of participation. All deicers were male because that represents the large majority of the deicer population in Montreal and Toronto. We classified deicers into three different experience levels: P1, P4, and P9 were inexperienced deicers (1 year- 2 years), P3, P5, P7, and P8 were mid-experience deicers (7-8 years), and P2 was an experienced deicer (24 years). The experience level of one of the deicers (P6) was not documented. The different experience levels of the participants has no impact on the results.

We assigned the nine deicers to one of three groups, which rotated through the three conditions (human deicer, GIDS 1, and GIDS 2) throughout the study. All deicers were current on the procedures and techniques employed during visual and tactile post deicing inspections. GIDS manufacturers conducted training sessions with all deicers one day prior to the start of the test.

Deicers provided demographic information to the research team using the questionnaire in Appendix A. All deicers also received and filled out a consent form (see Appendix B) upon arrival. Bilingual administrative personnel translated most forms from English to French to assist comprehension by the three deicers whose primary language was French (a French version of the translated documents immediately follows the English versions in the appendix).

Far visual acuity, color blindness, and tactile discrimination ability were determined for the inspections. Far visual acuity was determined using a 20 foot Snellen Eye Chart. Deicers' 1, 3, and 8 corrected vision was worse than 20/20 (measured at 20/25, 20/40, and 20/25 respectively). All had normal color vision as determined by the Quick Six Color Vision Test.

Tactile discrimination ability was determined with the Grit Ordering Test (GOT), which was developed specifically for this series of experiments. For the GOT, deicers were asked to indicate the order of roughness of three sandpaper strips (400, 600, and 1500 grit), from least to most rough. The strips were 1 in x 2.5 in (see Figure 1). P2 failed the task. The data from this participant was within the range of the other participants and did not affect the data.

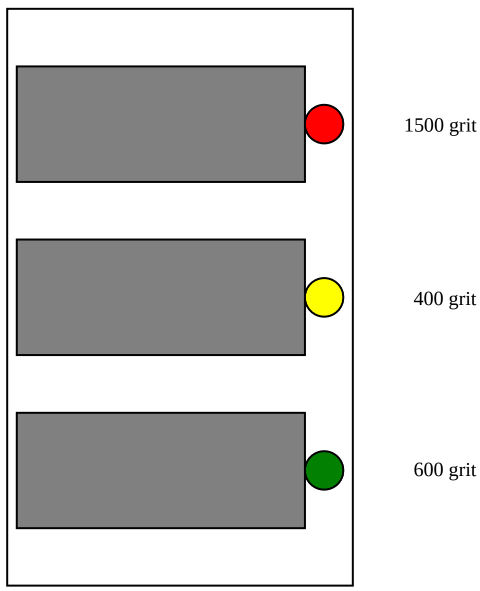

Figure 1. Grit Ordering Test on a 3 in x 5 in card showing 1 in x 2.5 in strips of different grits. The colored dots were used by the deicer to identify the strip (e.g., red is first, yellow is second, etc.)

Deicers that had experienced cold related illnesses or injuries, or had health conditions that may have predisposed them to cold related illnesses, were excluded from participation. Exclusion was determined through the information obtained from the Background Questionnaire (see Appendix A). In the interest of safety, we suggested a minimum clothing requirement for all deicers [see Appendix C (table adapted from FM 31-70)] designed to protect deicers down to -60° C (Castellani, O'Brien, Baker-Fulko, Sawka, Young, 2001). This list of clothing was sent to deicers before the experiment. Clothing that provides similar protection was also accepted. Extra clothing was available at the test site in case deicers failed to wear enough protection.

3.1.2 Research Personnel

The Test Administrators (TAs) were Human Factors (HF) researchers from the Simulation and Analysis Group of the FAA WJHTC and a French-speaking researcher from APS Aviation Inc. The TAs presented briefings, administered questionnaires, proctored the sessions, and conducted debriefings. The TAs adhered to the same clothing requirements listed for deicers.

3.2 Laboratory Environment, Equipment, and Instruments

3.2.1 Study Environment

We conducted this study in the large PMG Test and Research Centre climatic chamber in Blainville, Quebec, Canada. The climatic chamber dimensions were 54 feet long x 21.5 feet wide x 13 feet high. Environmental conditions from the threshold study were repeated because they proved to be safe and because performance comparisons could be made. The temperature in the chamber was -5° C (±.5°), humidity was 90% (± 5%). No precipitation was used. We attempted to replicate dusk/nighttime conditions. In order to accomplish this, two Subject Matter Experts (SMEs) viewed a number of different lighting scenarios and advised that the combination of two diffused, 150-watt high pressure sodium bulbs with approximately 14,000 mean lumens were appropriate to light the chamber. A Lockheed JetStar wing was mounted 4 feet from the floor in order to approximate the wing height of a regional jet aircraft. A diagram of the room setup along with specific dimensions is located in Appendix D.

Typically during an open deicing basket visual inspection, the deicer would move down the length of the wing in order to see it from several locations immediately following the application of deicing fluid. In a best case scenario the deicer would be about 5 feet from the wing. The basket would allow for vertical movement but limit the deicer’s lateral range of motion. The GIDS, typically mounted above the deicer’s head on the deicing boom, would move along the length of the wing with the deicer to examine the wing from different locations. However, due to limited space in the chamber, the GIDS cameras were mounted in a fixed location throughout the test, limiting the systems to one distance and angle. In order to be fair, we required that the human deicers perform their visual inspections from a fixed point collocated with the GIDS. Visual inspections were performed from a scissor lift five feet from the wing allowing the deicer limited lateral movement. Deicers were free to move the scissor lift vertically if they chose. In addition, the deicer was free to do their inspections from the angles they normally use during post deicing inspections (i.e. they could crouch or swivel). The distance and angle of the tactile inspections varied as the deicers walked around the wing to perform this inspection. Deicers were allowed to visually scan the wing as they conducted their tactile trials if they chose to do so. No tools were supplied to assist the operators in the inspections (e.g. ladders, stools, flashlights, or tactile wands).

The GIDS sensors were mounted in the same general location as the human deicer for each inspection. Camera height simulated an operational scenario in which the GIDS would be installed on top of an enclosed bucket or on the open deicing boom, approximately 3 feet above the average operator’s head. Output for each GIDS manufacturer was transmitted to their own remote station. GIDS stations were arranged so that inspections were performed independently and deicers could not see each other's output. Figure 2 shows the placement of both GIDS and the scissor lift overlooking the wing in the chamber.

Figure 2. Placement of the GIDS systems, scissor lift, and wing in the chamber. Image was taken during preparation for the experiment.

3.2.2 GIDS Systems

3.2.2.1 MDA Ice Camera

MDA developed The Ice Camera, a system utilizing a multi-spectral infrared camera that detects both ice and water. The Ice Camera employs a reflectance spectroscopy technique to detect ice 0.5 mm or thicker (Gregoris, Yu, & Teti, 2004). Figure 3 is an example of an Ice Camera image that shows a wing that is contaminated with ice. The Ice Camera is able to remotely detect ice and display the images, like the one in Figure 3, to enable the deicer to determine if the wing is still contaminated.

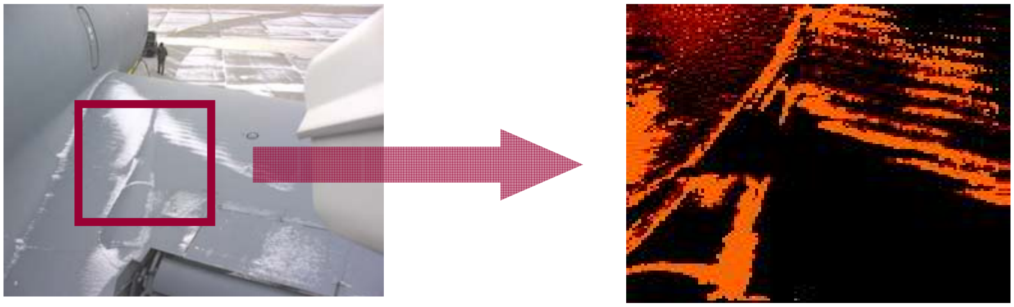

Image of aircraft wing

Ice is displayed as red overlay
on a greyscale image

Figure 3. MDA image of an aircraft wing with ice.

3.2.2.2 Goodrich IceHawk®

Goodrich Aerospace developed the Goodrich IceHawk®, a GIDS that uses a collimated laser light source to illuminate a small spot on the surface to be scanned with linearly polarized light. If light is reflected from this spot and is still linearly polarized the surface is categorized as clean. However, if the reflected light is de-polarized in a certain way, the surface is considered contaminated with ice, frost, or snow. A series of these spot images are taken with a raster mirror to provide a camera field of view of 30° X 20° using 60,000 spots or pixels for a 300 X 200 pixel image. Figure 4 depicts the output of a contaminated wing using the IceHawk®.

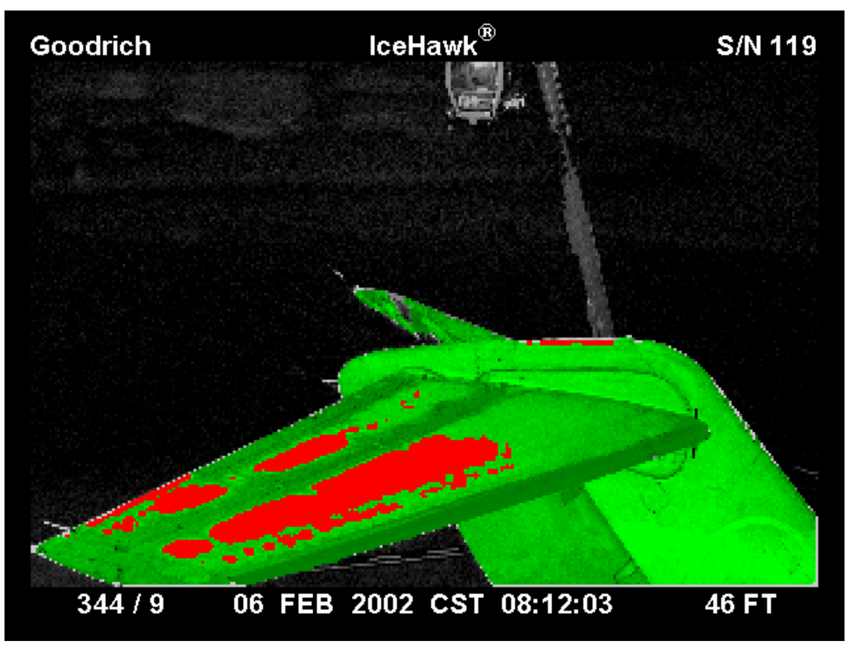

Figure 4. Goodrich IceHawk® image of a DC9 horizontal stabilizer with ice.

When there is no ice present, the scan will show a green scale image of the area examined. When ice, frost, or snow is present, the image will display red in those areas where the frozen contamination is present.

3.2.3 Ice Sample Characteristics

APS Aviation Inc. formed ice patches of different location, sizes, and thickness on an aluminum JetStar wing (as depicted in Figure 5). We applied a layer of diluted Type I deicing fluid[1] over the entire wing, including the ice patches, in order to simulate post deicing ice conditions. Ice patches were smooth with little to no edge. As in the field, ice smoothness and waviness were random. The ice patches varied with respect to size and thickness. We chose patch sizes and thicknesses that had low and moderate chances of being detected by the deicers. SMEs estimated that 8 inch and 16 inch diameter ice patches were adequate for the low range and moderate range, respectively. Furthermore, the 8-inch diameter ice patch was used because it correlated to the area frozen contamination must cover to constitute a deicing failure during deicing fluid holdover time testing. Ice thickness varied among two ranges, 0.3 - 0.5 mm and 0.6 - 0.8mm. (For details about ice sample preparation, see Narlis, 2005.)

Figure 5. APS forming a 16 inch patch on the JetStar aluminum wing.

3.3 Safety Precautions

Deicers were scheduled for experimental sessions of no more than eight hours, including a one-hour lunch break. Deicers were not in the cold chamber for more than five minutes per trial. They then rested in a warm room for a minimum of two hours while the wing was prepared for the next trial. Resting between trials provided a consistent warm-up period for the deicers and

[1] Type I deicing fluid is used by the participants everyday while performing their job. A 50-50 solution of water and deicing fluid is typically used. For this study, UCAR Ethylene Glycol (EG) ADF was used, diluted to a Brix of 11° (freezing point of approximately -7°C). See Appendix E for material safety information.

limited their time in the cold chamber[2]. This rest period is well within the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA; 1998) recommendations for the environmental conditions. With the breaks scheduled, and the temperatures to which the deicers and administrators were exposed, there was little danger of cold related injuries or illnesses according to OSHA's Cold Stress Equation (Appendix F). Furthermore, our exposure limit of five minutes or less is supported by guidelines from the U.S. Army Research Institute of Environmental Medicine (n.d.). They combine wind chill risk with work intensity and recommend rest periods every 15 to 20 minutes, for sedentary work, under much colder conditions (-34° C) than our deicers experienced.

Hypothermia prevention measures were taken. We described the environmental conditions, potential cold-induced illnesses and injuries (e.g., frost bite and hypothermia), and emergency procedures[3] to the deicers. We then reviewed the signs and symptoms of cold-induced illnesses with the deicers during the initial briefing and looked for symptoms throughout the sessions (see Appendix F). Safe practices, such as wearing adequate protection and rest, were enforced by all TAs.

3.4 Post Deicing Operational Procedures

The following describes the procedures used in the test for post deicing visual, tactile, and GIDS tests. Aero Mag and Globe Ground employ somewhat different procedures for completing visual and tactile inspections. However, the basic standards are similar. For clarity and standardization, the procedures used during the test were outlined.

3.4.1 Operational Procedures for Ground Crew Deicers

Visual inspections were conducted from a scissor lift located at a fixed location in the chamber. Deicers were allowed to vary their viewing angle by raising and lowering the lift as well as swiveling and crouching. They could not leave the confines of the viewing platform. Deicers were supplied with a laser pointer and were instructed to find as many ice patches as possible visually. When located, they pointed to specific areas of contamination with the laser pointer only after they made a decision that ice was present. They were not allowed to search with the laser. They were asked to conduct the inspection as quickly and accurately as possible, but were allowed to take as much time as they needed.

Tactile inspections were performed as deicers would in the field. They were instructed to use open hand only, without scratching, to preserve the test samples. Deicers were allowed to begin the inspections at whatever part on the wing they begin with in the field. All tactile inspections were performed with gloves on. Deicers were allowed to visually inspect the wing as they performed the inspection because they are able to do so in the field. They could reach as far into

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[2] Test Administrators relieved each other from the chamber every twenty minutes. This amount of time was still within the margin for safe exposure described in this paragraph.

[3] The test administrators were planned to be the first to respond to medical emergencies, since they were in the immediate vicinity. If an emergency arose from poisoning, frostbite, or hypothermia, first aid procedures detailed in Appendices E and F, respectively, were to be followed. These procedures were posted at a convenient place at the test site. The PMG Safety Department were planned to be the second to respond. They had an eyewash, warm blankets, warm water, and first aid kits available. Their phone number was posted at the site (see Appendix G).

the wing as they chose, but no stools or equipment were provided to help them extend their reach.

3.4.2 MDA Ice Camera Operating Procedures

3.4.2.1 System Description

MDA's Ice Camera system provided a human operator an indication of the kind, degree and location of the surface ice contamination. The system, shown in Figure 6, consists of a weather resistant sensorhead, which includes the multispectral camera, an infrared illuminator, and an operator display and controller (not shown). The Ice Camera used in these tests is a technology demonstrator based upon an early prototype but enhanced with a new illumination system.

Figure 6. MDA Ice Camera technology demonstrator system on a Pan-Tilt Unit.

As shown in Figure 7, the Ice Camera is mounted on a Pan Tilt Unit (PTU) and positioned to view the wing surface from above. The system has a limited field-of-view so the entire wing surface must be scanned by panning and tilting the camera using the PTU. The system can be aimed up/down/left/right by moving the joystick in the desired direction. The Ice Camera is aimed by positioning a square bull's eye box in the color video display over the area that is to be inspected. Once the box is positioned and the camera has stopped moving, then ice observations are made by looking at the Ice Camera display.

Figure 7. Ice Camera location in test chamber.

3.4.2.2 User Interface

The MDA Ice Camera's user interface is shown schematically in Figure 8. The interface consists of two displays: a wide-angle color video display of the scene and the Ice Camera display of the inspected surface.

The color video display was used for aiming the Ice Camera. The display has a square bull's-eye which outlines the region that the Ice Camera views. The Ice Camera display is a grey scale image of the surface with ice color-coded as a red overlay. A small circular bull's-eye is used to refine the aim.

Areas of the scene that are either overexposed or underexposed were highlighted in the display as flashing black or white regions.

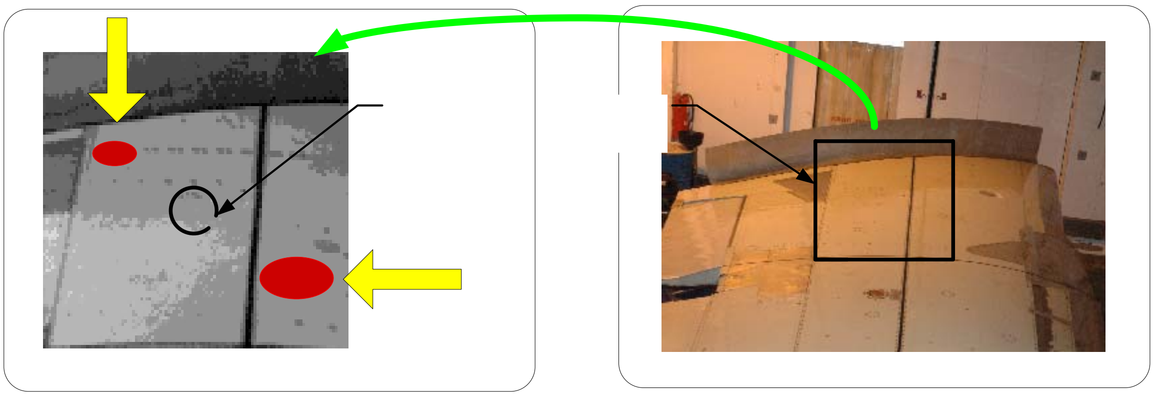

Figure 8. User interface.

3.4.2.3 Using the Ice Camera for wing contamination inspection

The following guidelines were provided to deicers for the use of the camera during aircraft wing inspection.

Basic inspection procedures

1. Aim the camera at the wing by looking at the color video display and adjusting the PTU joystick until the square bull's-eye box is positioned over the region that requires inspection.

2. Once the camera has stopped moving, look at the Ice Camera display. The flashing circular bull's-eye should be centered on the area that is to be inspected. The inspected area should not have any flashing black/white areas as these signify over/under exposure. To inspect areas that are flashing over/under exposed merely aim the bull's-eye near the region. An image should appear within a second and any detected ice will be shown as a red color overlay on the Ice Camera display.

3. Observe the image for several seconds and accurately record the locations of consistently red areas on the image of the wing surface.

4. Repeat the above steps to inspect the complete wing surface. To ensure complete inspection coverage the wing should be scanned in a consistent pattern with small overlaps between images.

    - The Ice Camera can only view a small portion of the wing at one time so to inspect the entire wing surface the camera view must be scanned along the wing in a consistent scan pattern. A possible scan pattern is shown in Figure 9. To ensure all the detected ice patches are seen by the operator it is very important that the pattern be followed and that the locations of the detected ice patches are recorded as accurately as possible. Failure to follow the pattern may lead to areas of the wing remaining uninspected and inaccurate ice patch locations may lead to miscounting patches.

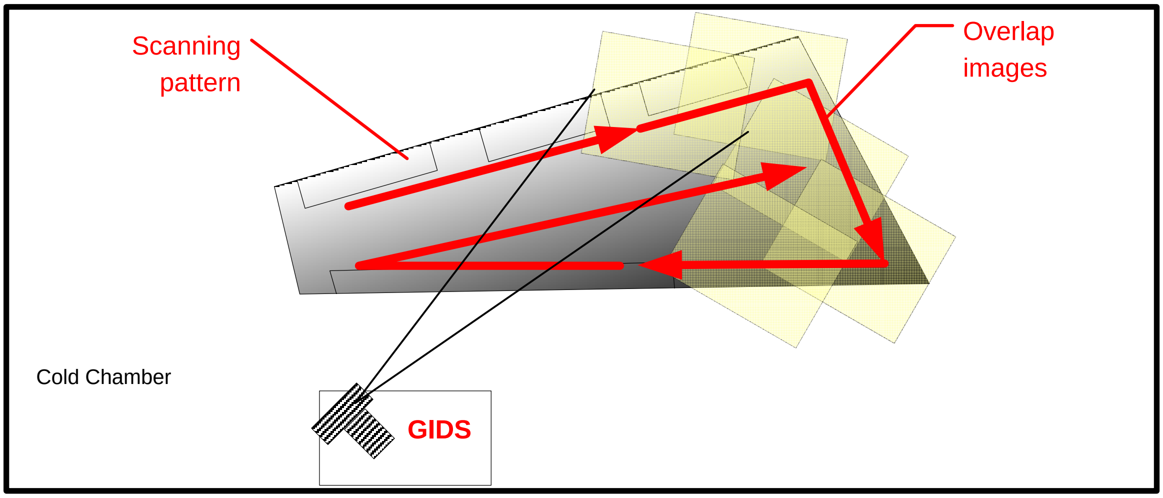

Figure 1. Possible scanning pattern for wing inspection.

1.1.1 Goodrich IceHawk® Operating Procedures

Three images were present on the Goodrich display at any given time. One of the images was a real-time scanning of the wing; this image was not for the purpose of interpretation. The other two images worked in tandem as interpretable output. The deicer viewed the two interpretable images that were displayed on the LCD screen. Where there was green, there was no ice present. Output displayed in red denoted that ice was present (Items such as rubber or glass may give false positive indications of ice presence. This was covered in training). **Error! Reference source not found.** is an example of a contaminated DC 9 stabilizer as shown by Goodrich's IceHawk®. The red portion of the image denotes ice.

It was necessary to move the IceHawk® using a pan/tilt mechanism and a joystick to inspect the entire wing. To do this, the deicer had to move the mechanism and scan the wing until the entire wing was assessed and determinations could be made about the presence of ice.

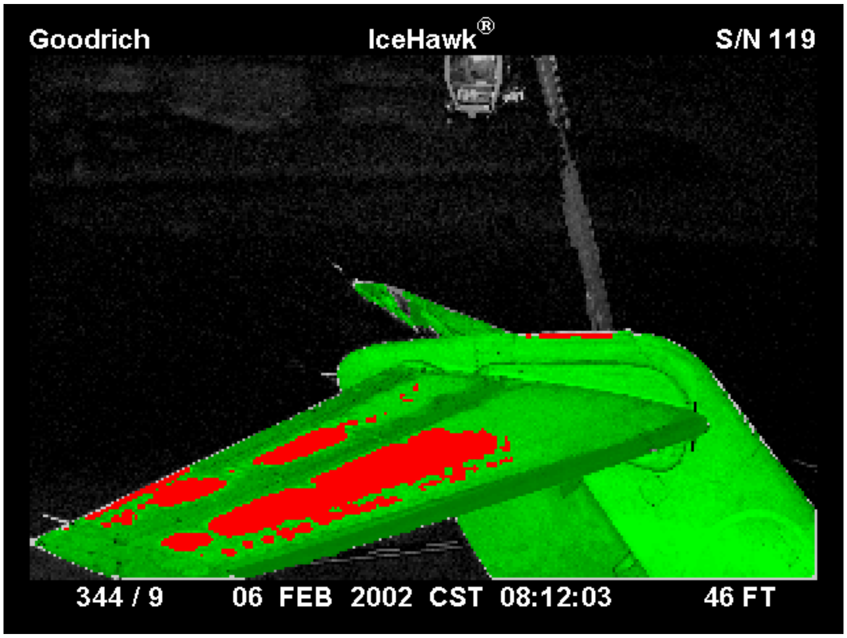

Figure 10. Goodrich IceHawk® image of a DC9 horizontal stabilizer with ice.

4. Test Design

4.1 High Contamination Test Design

The High Contamination test was designed to assess general visual and tactile inspection performance. The test was not entirely realistic in that it would be unlikely that a wing would have 12 patches remaining after deicing. However, the test was designed to allow more variability in performance than the Low Contamination test. The High Contamination study required that 12 ice samples be placed on the wing in various locations. For each test, the ice patches were randomly placed in 12 of the 187 grid point locations. The SME's adjusted these locations slightly to make sure critical areas were adequately represented (see Figure 11). SME's indicated that the patch sizes would have a low and moderate chance of being detected by deicers (8 inches and 16 inch in diameter, respectively). Ice thickness varied between two ranges, .3 -.5 mm and .6 -.8 mm (The ice thickness range within each of the thickness groups was a result of the process of making the ice samples). All four possible patch size and thickness combinations were placed on the wing at the same time.

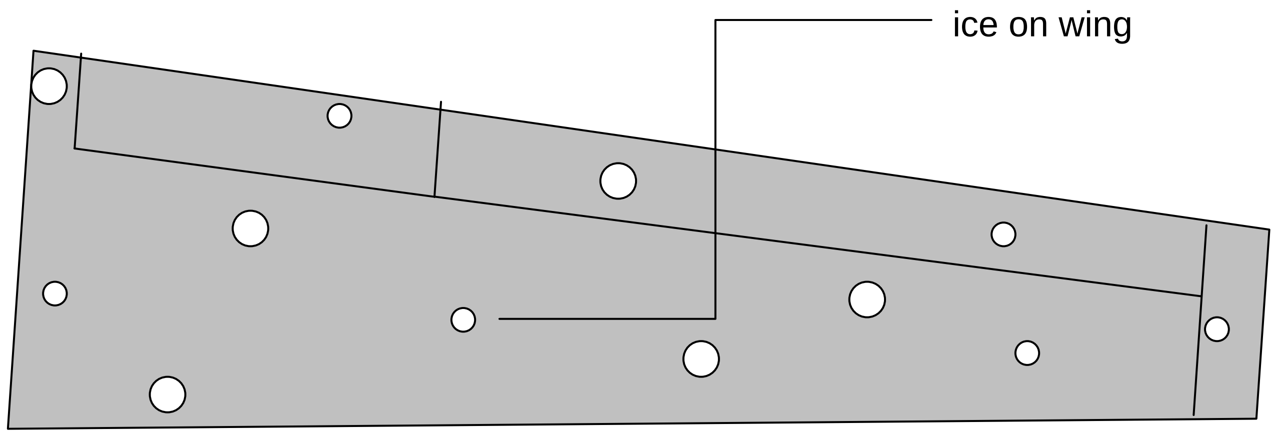

Figure 11. An example of ice patch placement for the High Contamination Test.

The study employed a within-subjects design, meaning every deicer experienced each condition. The conditions were considered to be control (or current detection system), GIDS1 and GIDS2. Table 1 summarizes the experimental design; it represents the within-group design for both *Patch Size* [diameter with two levels] and *Thickness* [with two levels]. Treatment condition order, subject order, and manufacturer order were counterbalanced for order (sequence) effects.

Table 1. High Contamination Study Design

	Patch Size (diameter)	
Patch Thickness	Low probability of detection (8 inch diameter)	Moderate probability of detection (16 inch diameter)
Low probability of detection (.3-.5 mm)	3	3
Moderate probability of detection (.6-.8 mm)	3	3

4.1.1 High Contamination Test Procedure

Deicers were sorted into groups of three and assigned to a condition each day. They rotated through each condition on successive days in order to experience each one: for example, as depicted in Table 2, deicers 1 through 3 were in the control condition (deicer) on Day 1, in the GIDS 2 condition on Day 2, and the GIDS 1 condition on Day 3.

Table 2. Deicer Assignments

	Ice Detection System		
Day	**Control**	**GIDS 1**	**GIDS 2**
Training	1-9	1-9	1-9
1	1-3	7-9	4-6
2	7-9	4-6	1-3
3	4-6	1-3	7-9

The day prior to the start of the study was dedicated to training and briefing the deicers. The GIDS manufacturers delivered a hands-on training package to all deicers. Neither the trainers nor the TAs revealed the manufacturers of the equipment. GIDS systems were referred to simply as GIDS1 and GIDS2 throughout the study. They are also referred to as such in the results section of this document.

Members of the HF Team briefed the deicers in a classroom setting. The visual and tactile screening tests were administered at this time. Questions were encouraged. The briefing covered the following topics:

1. Safety briefing
2. Deicer roles
3. GIDS operator roles
4. Study objectives
5. Study methodology
6. Rules and procedures
7. Laboratory equipment and configuration
8. Human Research Minimal Risk Consent

Following the briefing, the deicers and GIDS operators completed the Human Research Minimal Risk Consent Document contained in Appendix B. The deicers were then taken into the chamber to review the visual and tactile inspection procedures. They were also trained to use the scissor lift at this time.

In the briefing and throughout the test, we told the deicers and GIDS operators to perform the visual, tactile, and GIDS tests as quickly and accurately as possible, in an effort to replicate the pressures experienced in the field. We stressed that we would be collecting timing and accuracy data. Count-up timers were located in both the chamber and GIDS stations in order to keep deicers apprised of the time taken and to add stress.

The deicers individually entered the chamber and proceeded to the scissor lift platform. Once there, we asked them to face the wall away from the wing. We then instructed the deicer to "Begin" and started the count-up timer. At this time the deicer turned and began to identify as many of the patches as possible using only visual means. The deicers were allowed to vertically adjust the platform. We asked the deicer to point specifically to each spot of contamination with a laser pointer. The use of the laser pointer was only permitted when the deicers made their final determination that ice was present. We recorded the location of any contamination on a diagram of the wing (Appendix H). False alarms (an indication of ice where there was none) were also recorded. After the visual inspection was complete, we recorded the total visual inspection time and performed a brief interview (Appendix H). Figure 12 depicts a visual inspection being performed in the chamber.

Figure 12. Example of a deicer performing a visual test inspection.

Upon completion of the visual test interview, the deicer stepped down from the platform and performed a tactile test regardless of whether he reported the presence of ice. The tactile test required that the deicer approach the wing and perform a complete inspection. The deicer was again asked to make determinations about the existence of ice as he performed the inspection. During this process, we checked off the locations of the identified patches on a second diagram of the wing. When finished with the tactile inspection, the deicer called out “Done”. Upon completion of the visual and tactile tests, we logged the total time taken to perform the inspection, conducted a brief interview (Appendix H), and queried the deicer about any unclear information. The deicer then left the test area to complete a NASA Task Load Index (TLX; see Appendix J; Users Manual Vol. 1, n.d.). Figure 13 shows an example of what a tactile inspection looked like during the testing.

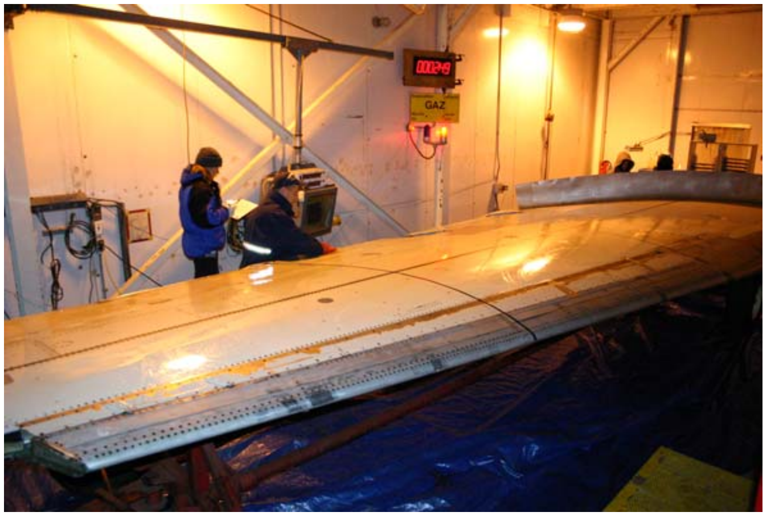

Figure 13. Example of a deicer performing a tactile test inspection.

After the deicers left the chamber, both GIDS operators began to perform their inspections. They were not required to enter the chamber, as images were transmitted remotely to independent stations. Each station was set up with all of the necessary manufacturer equipment required to capture and display the images (Figure 14 shows the setup for both GIDS stations as configured for the test). To begin, we started the count-up timer and instructed the operators to begin their inspection. As the operators scanned the wing and interpreted the GIDS output, the deicers marked the location of the ice as accurately as possible on a printed diagram of the wing (Appendix I). The wing was divided into sections with tape. Markings on the diagram represented these sections to help deicers to mark ice locations as accurately as possible. When their inspections were complete each deicer called out "Done" at which time we logged the total time taken to perform the inspection for each GIDS manufacturer.

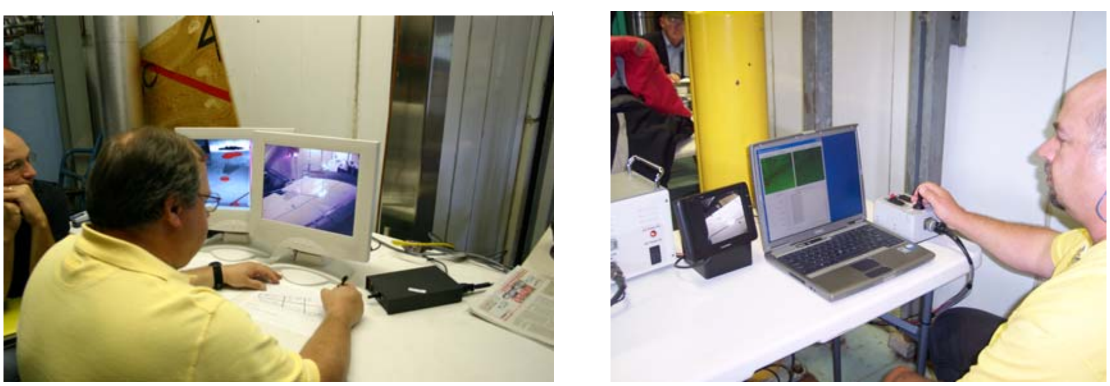

Figure 14. Example of deicers performing GIDS inspections from each GIDS station.

Upon completion of the GIDS evaluations, we queried them about any unclear information. The GIDS operators then completed the NASA TLX. The diagram in Figure 15 illustrates the test setup for the deicers and GIDS operators.

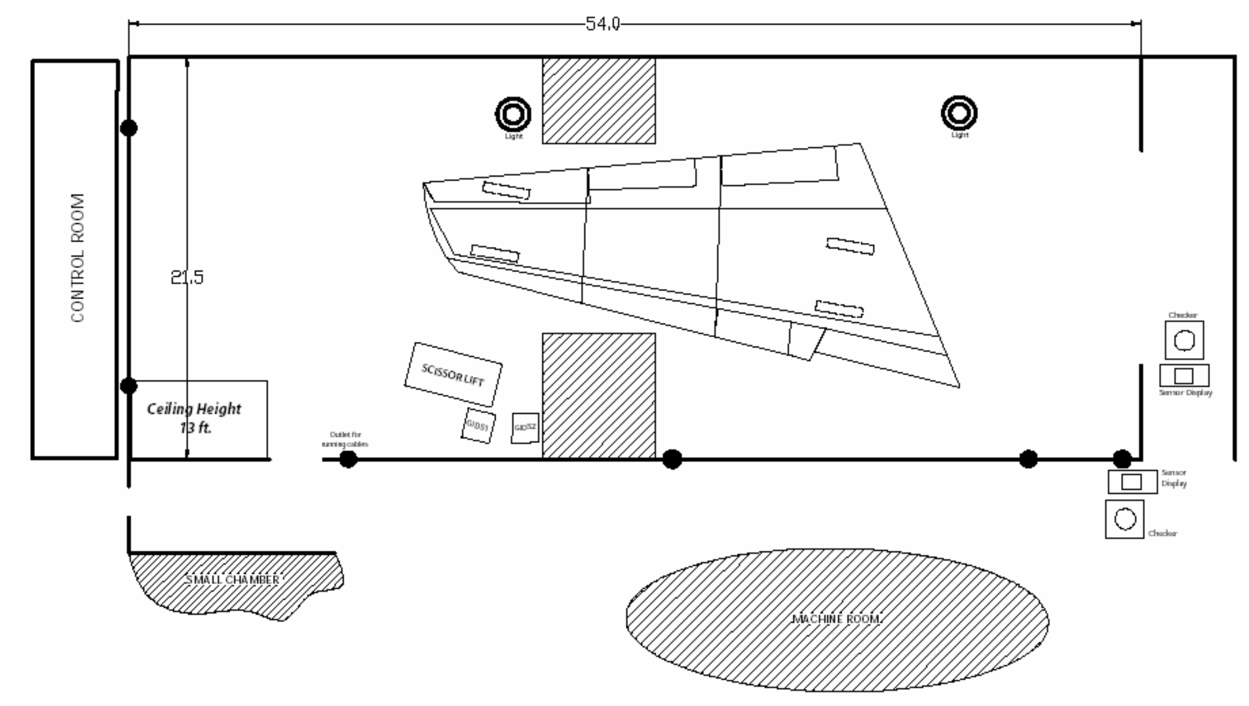

Figure 15. GIDS operator and deicer test setup.

Deicers filled out a Post Test questionnaire at the end of each day (e.g. a Visual and Tactile, GIDS 1, or GIDS2 questionnaire; Appendix K) in order to capture their opinions on various aspects of each ice detection method. After the study was complete they were given their test results and offered an opportunity to review and revise their Post Test Questionnaires. We then briefed deicers on the study design and asked for feedback about the test.

4.2 Low Contamination Test Design

This portion of the test was designed to be a more realistic post-deicing scenario. It consisted of three trials with three ice patches placed on the wing: one on the leading edge, one on the trailing edge, and one on the center of the wing (see Figure 16). The center of the wing, leading edge, and trailing edge were contaminated in one of three potential spots to avoid learning effects (depicted in Figure 16 as C1, C2, and C3 for the center of the wing; L1, L2, and L3 for the leading edge; and T1, T2, and T3 for the trailing edge). The sites for potential contamination were selected by SMEs during the pre-tests to be realistic locations. The size of the ice patches varied among two conditions, 8-inch and 16-inch diameters. Ice thickness varied between the values of .3-.5 mm and .6-.8 mm. Three patch size and thickness combinations were intended to be placed on the wing for each trial: one 8 inch patch, .3-.5 mm thick; one 8 inch patch, .6-.8 mm thick; and one 16 inch patch, .3-.5 mm thick. The locations of each patch were randomly assigned to each of the locations discussed in this section.

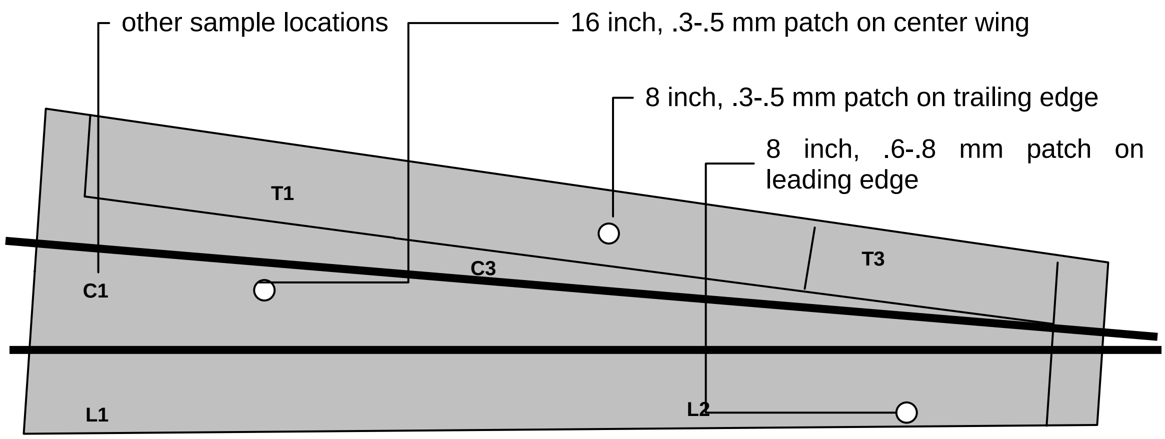

Figure 16. Example of ice patch placement for the Low Contamination Test.

The study employed a within-subjects design, meaning every deicer experienced each condition. The conditions were considered to be control (or current system), GIDS 1, and GIDS 2. Table 3 summarizes the experimental design; it represents the within-group design for both *Patch Size* [with two levels] and *Thickness* [with two levels]. Treatment condition order, subject order and manufacturer order were counterbalanced for order (sequence) effects.

Table 3. Low Contamination Study Design.

	Patch Size	
Patch Thickness	Low probability of detection (8 inch diameter)	Moderate probability of detection (16 inch diameter)
Low probability of detection (.3-.5 mm)	1	1
Moderate probability of detection (.6-.8 mm)	1	

4.2.1 Low Contamination Test Procedure

The Low Contamination test was comprised of three trials over three days. This test was designed to provide a more realistic scenario of post deicing characteristics. Patches were placed in representative critical areas to capture a realistic sample of what performance may look like in the field. One trial was performed each day. The same procedures used in the High Contamination test were used to collect data for the Low Contamination test. Please refer to Section 4.1.1 of this document for a detailed description of the test procedure.

4.3 No Contamination Test Design

This test was comprised of three inspections performed on a clean, uncontaminated wing. One ice-free trial was performed each day. Deicers were not told to expect both ice-free and ice trials. For this test only diluted Type 1 deicing fluid was placed on the wing. The no-ice trials were designed to collect data on false detection.

The study employed the same within-subjects design as the High and Low Contamination tests. The conditions, treatment condition order, subject order, manufacturer order, and procedures employed for High and Low Contamination tests were used for the No Contamination test as well (see Section 4.1.1 for procedures).

4.4 Constraints and Assumptions

The RAWG acknowledged that many factors could affect ice detection capability. However, due to time and budgetary constraints it was imperative that limitations be placed on the data collection effort. The GIDS RAWG carefully selected the variables that were considered to be important to the task. The working group chose to simulate more challenging ice detection scenarios (i.e. dusk/nighttime conditions, no tools, clear ice with no edge, etc.) while making the environmental conditions applicable to common conditions. Therefore, we did not simulate precipitation, wind, or extreme temperatures in this study. It is important to note that the introduction of different environmental conditions and tools could change the detection capabilities of either the human deicers and/or GIDS systems.

Due to size constraints in the chamber it was necessary to limit movement for the GIDS systems, and therefore, the visual inspections as well. Normally both the systems and the deicers would have the ability move along the entire length of the wing and would be able to perform the inspection from different angles and distances. The GIDS operators would also be able to directly view the wing during GIDS operations instead of being isolated as they were during the test. Consequently, the data provided for these portions of the test are snapshots of the entire process, but useful comparisons can be made. It should be noted, however, that the results may not be applicable to conditions that differ from those simulated in this study and may not necessarily reflect true detection capabilities or time to complete data for visual, GIDS1, and GIDS2 inspections.

Lastly, the GIDS systems used for the study are not production systems and would require design changes in order to field them. The study focus was on the technology of the system rather than user interface and ease of use, although we encouraged deicer comments and suggestions for changes.

5. Results

We collected objective data related to all inspection methods and conducted statistical analyses to draw comparisons between deicer and GIDS performance. We conducted both parametric and non-parametric tests, as appropriate, in order to determine whether statistically significant differences existed between human performance, GIDS 1 performance, and GIDS 2 performance. We report descriptive statistics, when suitable. Brief explanations of statistical terms are located in Appendix L. Table 4 and Table 5 summarize the data collected for each method of inspection.

Table 4. Objective Data for Ground Crew Deicers

Data Type	Data Capture	Measure
Total visual inspection time	Total each trial	In seconds
Total tactile inspection time	Total each trial	In seconds
Patches visually detected	Total each trial	Number of correct responses, patch size, and patch thickness
Patches tactilely detected	Total each trial	Number of correct responses, patch size, and patch thickness
Erroneous identifications	During each trial	Number of false positives

Table 5. Objective Data for GIDS

Data Type	Data Capture	Measure
Total inspection time	During each trial	In seconds
Patches detected (GIDS 1)	During each trial	Number of correct responses, patch size, and patch thickness
Patches detected (GIDS 2)	During each trial	Number of correct responses, patch size, and patch thickness
Erroneous identifications	During each trial	Number of false positives

5.1 High Contamination Results

5.1.1 Accuracy

Visual and tactile inspections required that the TA's mark all detected contamination on a test administration form for each test. For GIDS inspections the deicers marked, as carefully as possible, the existence and location of all contamination found during each test session on a diagram of a wing. Times to complete each test were recorded on these forms as well. Scoring the test results was accomplished by comparing the deicers' data with the actual test diagrams and determining whether the locations of the detected ice patches were consistent with actual test scenarios. From this data we determined the number of correct detections (accuracy), false detections, and size, thickness, and location of the ice found for each method of inspection. Time stamps on test materials were used to compute and analyze time to complete an inspection for each method of inspection.

After verifying that the assumptions for the data were met, a one-way repeated measure Analysis of Variance (ANOVA) was conducted on the High Contamination data to determine if method of inspection had a significant effect on the correct number of ice patches detected. An alpha level of .05 was used for all statistical tests.

Results of the repeated measures ANOVA resulted in a significant difference between the methods of inspection for the number of correct number of ice patches found, $F(3, 24) = 23.59, p < .05$. Figure 17 summarizes the means of each method of inspection. Since there was a significant effect of inspection method found, pairwise comparisons were analyzed using the Least Significant Difference (LSD) method.

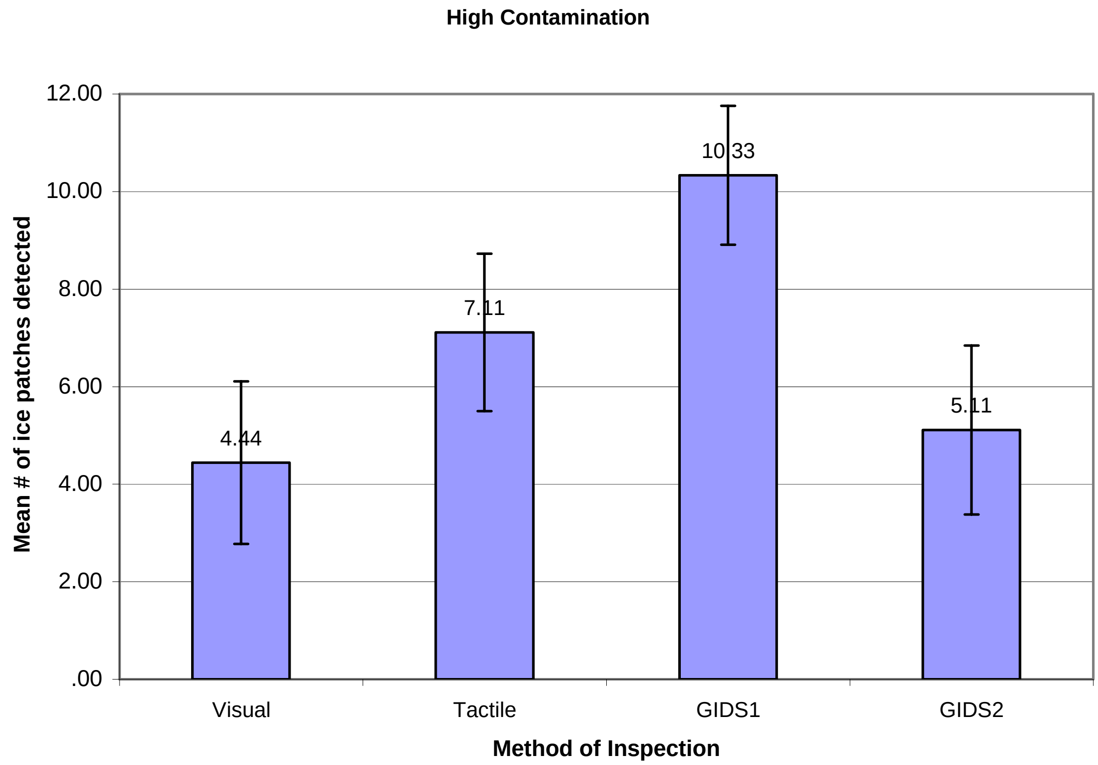

Figure 17. Mean number of ice patches detected for each method of inspection during the High Contamination condition.

Results for the significant pairwise comparisons revealed that particiapants using GIDS1 found significantly more patches (M = 10.33, SD = 1.73) than GIDS2 (M = 5.11, SD = 1.76), $p < .05$. Participants using the GIDS1 method found significantly more patches (M = 10.33, SD = 1.73) than the Visual (M = 4.44, SD = 1.67) and Tactile (M = 7.11, SD = 1.62) methods of inspection, $p < .05$. Participants using the Visual method found significantly fewer patches (M = 4.44, SD = 1.67) than the Tactile method (M = 7.11, SD = 1.62). $p < .05$. See Figure 17 for summary of data.

5.1.1.1 Summary of results

- GIDS1 accuracy scores (M = 10.33) were significantly better than Visual (M = 4.44), Tactile (M = 7.11), and GIDS2 (M = 5.11) inspections, $p < .05$.

- The Tactile method found significantly more patches than the Visual method, $p < .05$.

5.2 False Detections

The data for detecting an ice patch when there was not one present (false detection) was analyzed for the High Contamination test. A false detection was counted when there was no ice present on a specific location on a wing and the deicer indicated there was ice present.

Overall results indicated that the GIDS1 system had the least amount of false detections for the High Contamination test. For the GIDS1 condition, one patch was falsely detected by one person. The Visual condition resulted in three patches being falsely detected between two deicers (one deicer falsely detected one patch, the other falsely detected two). The Tactile condition also had three ice patches falsely detected by two different deicers (one participant falsely detected one patch, the other falsely detected two). GIDS2 had four falsely detected ice patches between three people (two participants detected one patch and the other detected two patches falsely).

5.2.1 Summary of results

The GIDS1 method resulted in the fewest false detections (one), followed by the Visual and Tactile method (three and three, respectively), and lastly GIDS2 (four).

5.3 Time to Complete Inspection

Time to complete the Visual, Tactile, GIDS1, or GIDS2 inspections was analyzed for the High Contamination condition. See Figure 18 for a summary of the data.

Figure 18. Mean Time to Complete the High Contamination inspection for each method of inspection.

The means and standard deviation for each of the methods (see Figure 18) of inspections were calculated. This data was analyzed using a repeated measures one-way ANOVA. The ANOVA tested the four methods of inspection. Since the test for sphericity was not met, we used a Greenhouse-Geisser correction for the overall main effect of Time for the analysis. Results showed that there was a significant difference between the four different methods of inspection on time to complete the detection process, $F(1.83, 14.63) = 82.99$, $p < .05$.

Since there was an overall difference in the first ANOVA, we performed pairwise comparisons using the Least Significant Difference (LSD) method.

Table 6 shows that all pairwise comparisons were statistically significant. Visual inspections took significantly less time than Tactile inspections (51.33 vs. 71.22 seconds), GIDS1 inspections (51.33 vs. 324.11 seconds), and GIDS2 inspections (M = 51.33, SD = 16.78 seconds vs. M = 243.00, SD = 77.49 seconds). Tactile inspections took significantly less time than GIDS1 inspections (M = 71.22, SD = 24.28 seconds vs. M = 324.11, SD = 50.00 seconds) and GIDS2 inspections (M = 71.22, SD = 24.28 seconds vs. M = 243.00, SD = 77.49 seconds). Finally, GIDS2 took significantly less time than GIDS1 (M = 324.11, SD = 50.00 seconds vs. M = 243.00, SD = 77.49 seconds).

Table 6. Pairwise Comparison *p* Values for Time to Complete the High Contamination Inspection.

Pairwise Comparisons by Method of Inspection	**p sig. value**
Visual vs. Tactile	.002
Visual vs. GIDS1	.000
Visual vs. GIDS2	.000
Tactile vs. GIDS1	.000
Tactile vs. GIDS2	.000
GIDS2 vs. GIDS1	.019

5.3.1 Summary of Results

- Visual inspections took the least amount of time (*M* = 51.33, *SD* = 16.78 seconds), followed by the Tactile inspections (*M* = 71.22, *SD* = 24.28 seconds), GIDS2 inspections (*M* = 243.00, *SD* = 77.49 seconds) and GIDS1 inspections (*M* = 324.11, *SD* = 50.00 seconds).

5.4 Patch Thickness Analysis

The data was analyzed to determine if any of the four methods of inspection were affected by patch thickness or diameter. A Friedman two-way analysis of variance by ranks test was done using the data from the High Contamination sessions to determine if a difference of correct patch detection existed between the methods of inspection for each type of patch. This nonparametric test was used due to the data represented in Figure 19 violating the normality assumption for parametric tests. This non-parametric test uses the ranks of the data rather than their raw values to calculate the statistic. Mean ranks were calculated for the Friedman test and are summarized in Table 7. The higher the mean rank score, the more ice patches were found for that particular method of inspection.

Table 7. Mean Ranks for Each Method of Inspection by Patch Type.

Mean Ranks	**Visual**	**Tactile**	**GIDS1**	**GIDS2**
.3-.5 mm, 8”	1.83	2.50	3.67	2.00
.6-.8 mm, 8”	1.89	2.61	3.28	2.22
.3-.5 mm,16”	1.78	2.78	3.61	1.83
.6-.8 mm, 16”	2.17	2.72	2.89	2.22

The detection performance of the different methods of inspection were not equal in finding the .3 - .5 mm, 8” patches. A significant overall difference was found for method of inspection for the thinner 8” patches, $F_r(3) = 14.69$, $p < .05$. As seen in the first row of Table 7, GIDS1 had the highest mean rank (3.67), followed by Tactile (2.50), GIDS2 (2.00), and Visual (1.83) methods.

The performance for the different methods of inspection also differed significantly for the .3 - .5 mm, 16” patches, $F_r(3) = 14.19$, $p < .05$.   The data in the third row of Table 7 shows GIDS1 with the highest mean rank (3.61), followed by the Tactile (2.78), GIDS2 (1.83) and Visual (1.78) methods.

For the thinner, 8” patches, a significant difference was found for GIDS1 vs. GIDS2, $F_r(1) = 15$, $p < .05$ and GIDS1 vs. Visual, $F_r(1)=16.5$, $p < .05$. The visual method found significantly less patches (Mean Rank = 1.83) than the GIDS1 method (Mean Rank = 3.67), $F_r(1) = 16.5$, $p < .05$.

For Low 16” patches, GIDS1 found significantly more patches than the Visual method (3.61 vs 1.78), $F_r(1)=16.5$, p<.05. GIDS1 found significantly more thinner 16” patches than GIDS2 (3.61 vs. 1.83), $F_r(1) = 16$, p<.05.

There were no statistically significant mean rank differences found between the methods of inspection for the thicker 8” and 16” patches, $p > .05$.

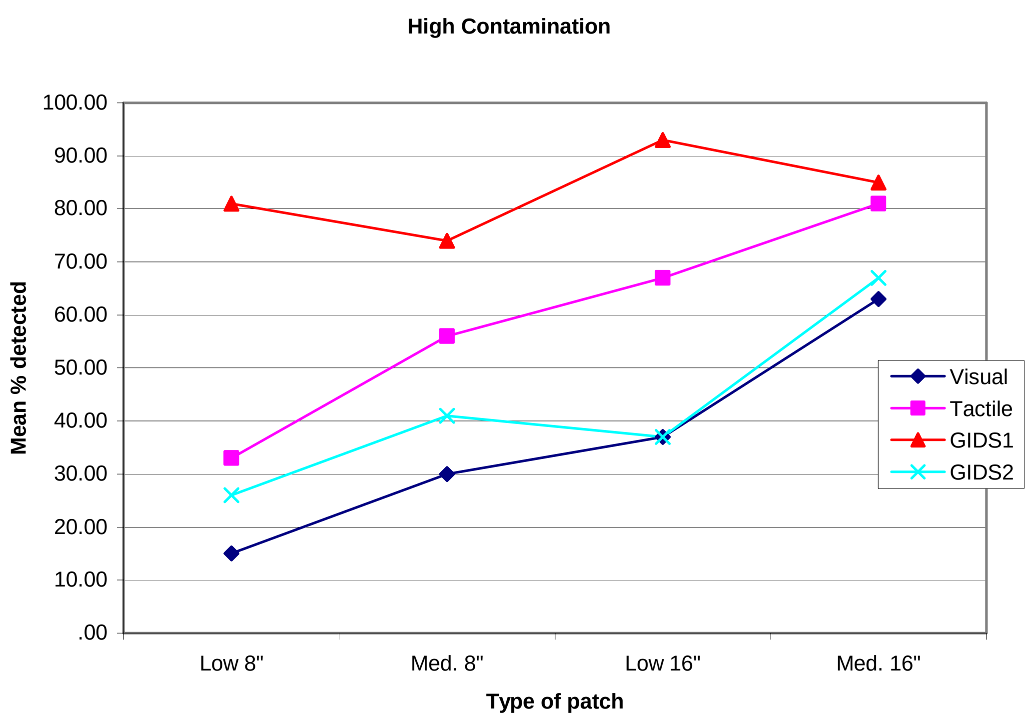

Figure 19. Mean percent correct detection of each type of ice patch for all methods of inspection.

As seen in Figure 19, as the patch type gets thicker and bigger in diameter, the detection rate generally increased, with the exception of the GIDS1 detection rate which was more stable and accurate in general than the other methods. GIDS2 performance was fairly similar to the visual condition.

5.5 Location Analysis

5.5.1 Detection Location Trends

The frequency with which each patch was missed was diagrammed for all tests and conditions (diagrams are located in Appendix M of this document). The purpose of this analysis was to identify whether trends may have existed for the area or location of either missed or detected patches. For example, we checked to see if the Visual condition resulted in more missed patches along the root of the aircraft since that was the farthest point from the scissor lift. No trends were apparent for any condition. Ice was not missed or detected in any area or location of the wing with any consistency for any method. This suggests that the location or area of the contamination was not a factor in detection.

5.5.2 Leading Edge Detection

Leading edge contamination poses the most significant threat to flight operations. Therefore, a separate accuracy analysis was conducted for the leading edge in order to determine whether leading edge detection was better or worse for any of the conditions.

Due to the limited and varied number of patches located on the leading edge for each High Contamination test, traditional statistical analysis could not be performed. Three patches were on the leading edge for the Day 1 High Contamination test, two patches for Day 2, and four patches for Day 3. Therefore, leading edge contamination was collapsed across all High Contamination tests for a total of nine patches overall. From this data, correct detections were reported using descriptive statistics, namely percentages. The range, or lowest to highest percentage detected, across all nine participants was computed as well to indicate the individual operator variability. For example, referring to Table 8 for the Tactile method, some operators detected one third of the patches whereas others detected all patches.

Overall GIDS1 had the most correct detections (92%) on the leading edge along with the most limited range. Tactile tests resulted in 61% leading edge detection rate, followed by GIDS2 (38%), and Visual (30%). Table 8 summarizes the data across all tests.

Table 8. Percentage of ice patches found on leading edge of wing for all nine participants

Method of Inspection	Percent correctly found	Range
Visual	30 %	0–100%
Tactile	61%	33–100%
GIDS 1	92%	50–100%
GIDS 2	38%	0–67%

6. High Contamination Test Discussion

6.1 Accuracy

The study compared the accuracy of all the methods in detecting contamination. The groups compared were Visual, Tactile, GIDS1, and GIDS2. Results showed that GIDS1 (M = 10.33) found significantly more patches than the Visual (*M* = 4.44), Tactile (*M* = 7.11), and GIDS2 (*M* = 5.11) methods.

It is possible that the GIDS accuracy scores include transcription errors and inspection coverage errors. One of the GIDS manufacturers noted that in some cases two adjacent patches were seen but the operator chose to mark them down as a single patch. Coverage errors also might have occurred when some areas of the wing were missed during the inspection survey using the GIDS systems.

6.2 False Alarms

False alarms were classified as finding an ice patch when none were present. Data collected for this category indicated that the GIDS1 system had the least amount of false detections for the High Contamination test (one false detection overall). Visual and Tactile methods were equally as likely to result in a false alarm (both had a total of three false detections). The GIDS2 method had a total of four false detections.

6.3 Time to Complete Inspection

Data analysis compared times to complete an inspection. Each of the comparisons across all four groups was significant. Visual inspections took the least amount of time (*M* = 51.33 seconds), followed by a tactile inspection (*M* = 71.22), GIDS2 (*M* = 243.00), and GIDS1 (*M* = 324.11).

It is important to note that the inspection times are a snapshot of the actual process and, therefore, do not reflect true inspection times. In the field, visual inspections would involve moving the truck down the length of the wing. Visual inspections were only conducted from one point for this evaluation artificially deflating time to complete inspection data. Furthermore, the TA, rather than the deicer, marked the detections on the diagram saving time. In contrast, GIDS inspections may have taken more time than a realistic field evaluation as time to diagram the detected contamination is included in the data that would not be necessary in the field. Deicers were also required to scan the entire wing using a pan/tilt joystick to conduct a comprehensive evaluation. It is possible that they may not have to conduct an inspection in this manner in a realistic setting.

6.4 Patch Size and Thickness Analysis

We conducted an analysis to determine whether the thickness or diameter of the patch affected detection for the four methods of detection. Results revealed that GIDS1 found significantly more of the thin (.3-.5 mm) 8 inch and 16 inch patches than both GIDS2 and Visual methods. There were no statistically significant differences between the methods of inspection for the thicker (.6-.8 mm), 8 inch and 16 inch patches. GIDS1 detection capability also appeared to be more stable no matter what the size and thickness of the patch, while the other methods detection capability appears to incline as a function of an increase in size and thickness.

6.5 Location Analysis

No trends appeared in missed or detected contamination location. Missed and detected contamination appeared to be scattered and random for each condition. No method was more or less likely to pick up contamination in any particular area or location on the wing.

A separate accuracy evaluation was conducted for leading edge detection since this is a considered a critical area for ice detection. Descriptive analysis indicated that the detections rate was consistent with the initial accuracy analysis. GIDS1 detected the most leading edge ice, followed by Tactile tests, GIDS2, and Visual tests.

7. High Contamination Test Conclusions

The GIDS1 was superior to visual, tactile, and GIDS2 in terms of accurate detections (across all four patch types) and false alarms, although it was slower in terms of time to complete inspections. The GIDS2 method was slightly more likely to result in a false alarm than the Visual and Tactile methods (which were equally likely to detect a false patch).

8. Low Contamination Results

8.1 Accuracy

Visual and Tactile inspections required that the TA mark all detected contamination on a test administration form for each test. For GIDS inspections the deicers marked, as carefully as possible, the existence and location of all contamination found during each test session on a diagram of a wing. Times to complete each test were recorded on these forms as well. Scoring the test results was accomplished by comparing the deicer's data with the actual test diagrams and determining whether the locations of the detected ice patches were consistent with actual test scenarios. From this data, the TAs determined the number of correct detections (accuracy), false detections, and the size and thickness of the ice found for each method of inspection. The resulting data and times to complete the tests were analyzed and compared. It should be noted that a medium thickness 16'' patch was inadvertently placed on the wing for the Day 2 Low Contamination trial instead of the medium thickness 8' patch. Since no patch size analysis was performed for this test, data analysis was not compromised.

For total patches detected for the Low Contamination condition, a non-parametric Friedman's analysis of variance by ranks test was used since the data summarized in Figure 20 did not meet the assumptions of normality to conduct parametric tests.

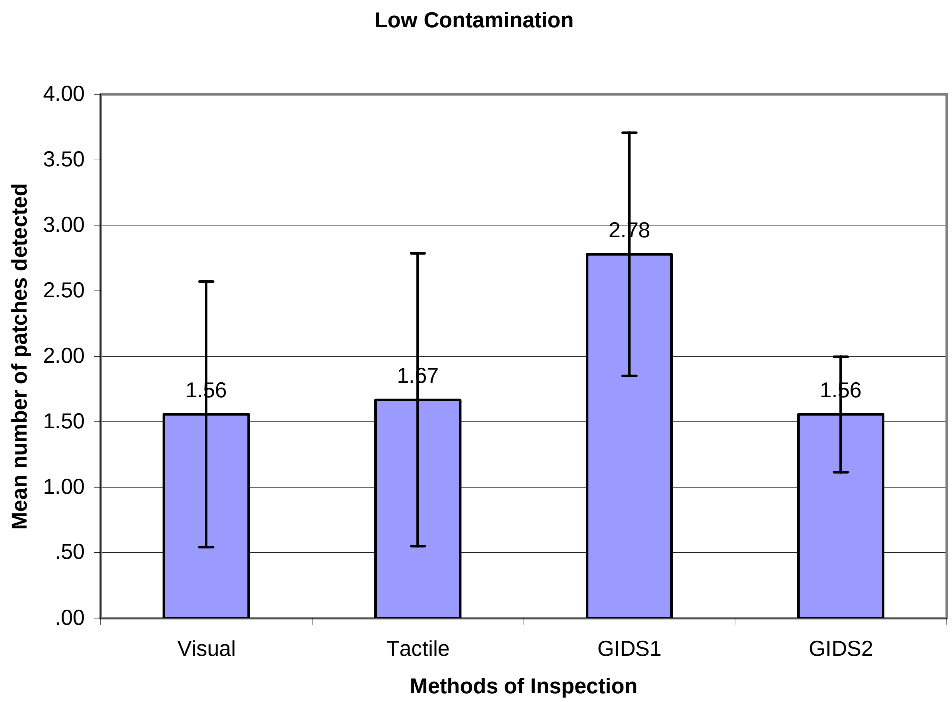

Figure 20. Mean number of ice patches detected for each method of inspection during the Low Contamination condition.

The Friedman's analysis of variance also resulted in a significant overall difference for the method of inspection variable $F_r(2) = 11.33$, $p < .05$. Table shows the mean ranks for each of the four methods of inspection for this analysis. Order of mean rank from highest to lowest was GIDS1 (3.61), Tactile (2.28), both Visual and GIDS2 (2.06). To identify where the group differences were located, a Friedman's test for multiple comparisons was used. No significant pairwise comparisons were found, $p >.05$.

Table 9. Mean Ranks for Each Method of Inspection.

Method of Inspection	**Mean Rank of patches found**
Visual	2.06
Tactile	2.28
GIDS1	3.61
GIDS2	2.06

8.1.1 <u>Summary of results</u>

The GIDS1 system found the highest number of ice patches, followed by the Tactile method, Visual method, and lastly the GIDS2 system.

8.2 False detection

False detection data for the Low Contamination condition was also analyzed. False detection occurred when a deicer detected a patch of ice that was not actually present.

The Visual condition resulted in the most false alarms. A total of 11 patches were falsely identified between four deicers (two participants detected two patches, the other two participants falsely detected three and four ice patches). The Tactile condition had a total of 4 false detections between three deicers. One deicer falsely detected one patch for the GIDS2 system. No deicers reported a false alarm in the GIDS1 condition for this test.

8.2.1 Summary of Results

The Visual condition resulted in the most false identifications (11), followed by the Tactile condition (four), GIDS2 (one), and GIDS1 (none).

8.3 Time to Complete Inspection

Time to complete the Visual, Tactile, GIDS1, and GIDS2 inspections was analyzed for the Low Contamination condition. The means and standard deviation for each of the methods of inspections for the Low Contamination condition were calculated (see Figure 21).

We analyzed this data using a repeated measures one-way ANOVA. The ANOVA tested the four methods of inspection (Visual, Tactile, GIDS1, and GIDS2). Since the test for sphericity was not met, we used a Greenhouse-Geisser correction for the overall main effect of time for the analysis. Results showed that there was a significant difference between the four different methods of inspection on time to complete the detection process, $F(2.02, 16.18) = 55.46$, $p < .05$. Order of time for method of inspection from quickest to slowest to complete was: Visual (M = 58.78, SD = 30.57 seconds), Tactile (M = 72.00, SD = 36.49 seconds), GIDS2 (M = 225.56, SD = 77.82 seconds) and GIDS1 (M = 264.33, SD = 63.32 seconds).

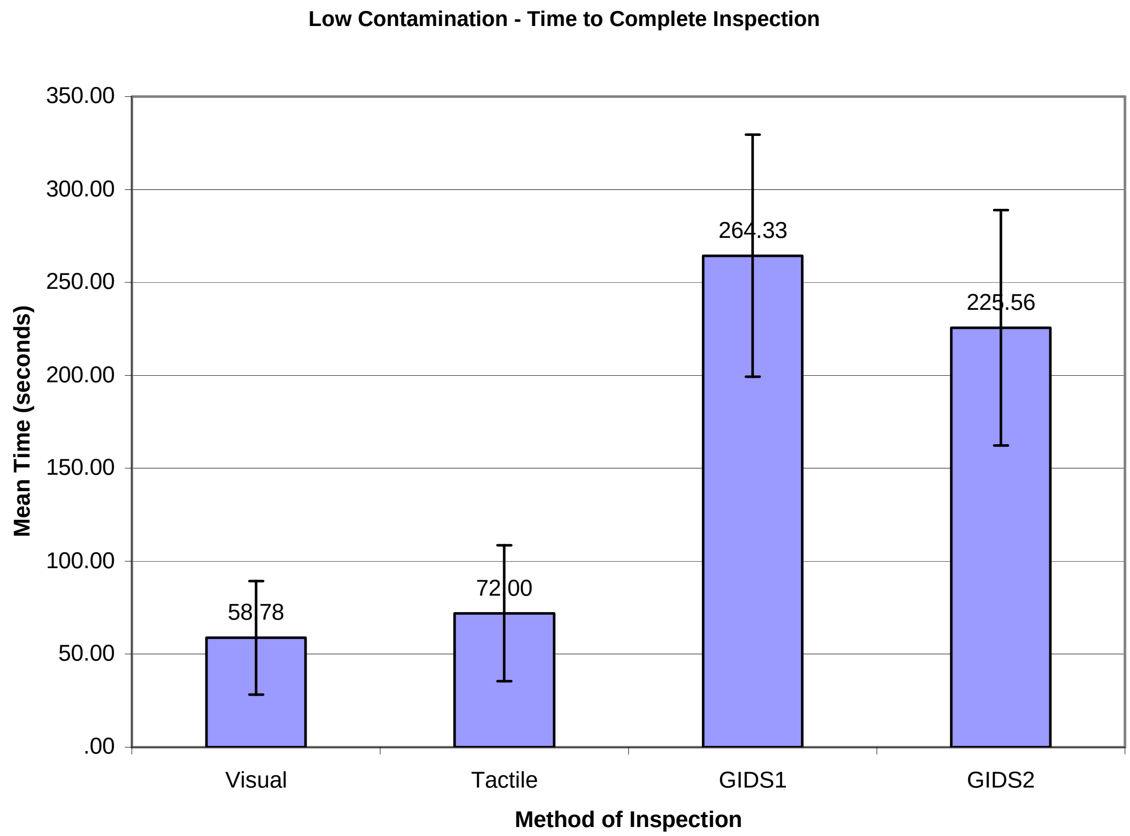

Figure 21. Mean Time to Complete the No Contamination inspection for each method of inspection.

We analyzed pairwise comparisons for the ANOVA using the Least Significant Difference (LSD) method. Table shows the results of the significant comparisons. The pairwise comparisons listed were statistically significant, $p < .05$. As you can see from Table , Visual inspection took significantly less time than Tactile (*M* = 58.79, *SD* = 30.57 seconds vs. *M* = 72.00, *SD* = 36.49 seconds) GIDS1 (*M* = 58.79, *SD* = 30.57 seconds vs. *M* = 264.33, *SD* = 63.32), and GIDS2 (*M* = 58.79, *SD* = 30.57 seconds vs. *M* = 225.56, *SD* = 77.82). Tactile inspections took significantly less time than GIDS1 (*M* =72.00, *SD* = 36.49 vs. 264.33, *SD* = 63.32 seconds) and GIDS2 (*M* = 71.22, *SD* = 24.28 vs. *M* = 225.56, *SD* = 77.82 seconds).

Table 10. Pairwise comparison p values for Time to Complete the Low Contamination condition

Pairwise comparisons by method of inspection	**p sig. value**
Visual vs. Tactile	.048
Visual vs. GIDS1	.000
Visual vs. GIDS2	.000
Tactile vs. GIDS1	.000
Tactile vs. GIDS2	.000

8.3.1 Summary of Results

Visual inspections took the least amount of time (*M* = 58.78, *SD* = 30.57 seconds), followed by Tactile inspections (*M* = 72.00, *SD* = 36.49 seconds), GIDS2 inspections (*M* = 225.56, *SD* = 77.82 seconds) and GIDS1 inspections (*M* = 264.33, *SD* = 63.32 seconds).

9. Low Contamination Test Discussion

9.1 Accuracy

The study compared the accuracy of all the methods (Visual, Tactile, GIDS1, and GIDS2) in detecting post-deicing contamination. Results revealed that the GIDS1 method detected the most patches. The Tactile method was second in terms of performance. The Visual and GIDS2 methods were equal in terms of performance for this test.

9.2 False Alarms

False alarms were classified as finding an ice patch when none was present. Participants using the GIDS1 system did not detect any false alarms for the Low Contamination test. One deicer falsely detected one ice patch using GIDS2. The tactile method resulted in four false detections between three separate deicers. The visual inspection resulted in the most false detections, a total of eleven (between four deicers).

9.3 Time to Complete Inspection

When all four methods of inspection were analyzed for total time to complete an inspection, the results were significant across all four groups (Visual, Tactile, GIDS1, and GIDS2). Visual inspections took the least amount of time, followed by a Tactile inspection, GIDS2, and GIDS1.

The same issues discussed in Section 6.3 are also relevant here in regards to the inspection process.

10. Low Contamination Test Conclusions

The results from the Low Contamination test were consistent with the High Contamination test. GIDS1 was superior to all other methods in terms of accurate detections and false alarms rates. The results for time to complete an inspection were also consistent with the High Contamination test. Visual and Tactile inspections were the fastest, followed by GIDS1 and GIDS2.

11. No Contamination Test Results

Visual and Tactile inspections required that we mark all detected contamination on a test administration form for each test. For GIDS inspections the deicers marked, as carefully as possible, the existence and location of all contamination found during each test session on a diagram of a wing. We recorded times to complete each test on these forms as well. All contamination recorded on these forms were automatically classified as a false positives for each method of inspection since there were no ice patches on the wing. False positive data and times to complete the tests were analyzed and compared. It should be noted that on Day 2, the last two

No Contamination runs could not be completed due to an equipment malfunction. Therefore, data for two GIDS1 No Contamination test runs were lost for deicers 5 and 6. Group means were substituted for the missing data in order to complete the analysis.

11.1 Accuracy

There was No Contamination present on the wing; therefore, only false alarm and speed data were analyzed for this test.

11.2 False detection

False detection data for the Low Contamination condition was also analyzed. False detection occurred when a deicer detected a patch of ice that was not actually present.

GIDS1 inspections resulted in no false detections. Tactile inspections were second, in terms of fewest detections (one false alarm), followed by Visual inspections (two false alarms between two participants). GIDS2 inspections resulted in the most false alarms (three false alarms between three participants).

11.3 Time to Complete Inspection

Time to complete the Visual, Tactile, GIDS1, or GIDS2 method of inspection was analyzed for the No Contamination condition. For the No Contamination time to complete inspection measure, the Visual, Tactile, GIDS1, or GIDS2 method of inspection was analyzed. The means and standard deviation for each of the methods of inspections were calculated (see Figure 22). The data from Figure 22 was analyzed using a repeated measures one-way ANOVA. The repeated measures ANOVA tested the four methods of inspection (Visual, Tactile, GIDS1, and GIDS2).

Since the test for sphericity was not met for the ANOVA, we used a Greenhouse-Geisser correction for the overall main effect of method of inspection for the analysis. Results showed that there was a significant difference between the four different methods of inspection on time to complete the detection process, $F(1.13, 9.06) = 30.20$, $p < .05$. From the data in Figure 22**,** GIDS1 took the longest (*M* = 247.00, *SD* = 18.59 seconds), followed by GIDS2 (*M* = 210.22, *SD* = 105.78), Tactile (*M* = 62.00, *S*D = 20.06) and Visual (*M* = 51.00, *SD* = 23.72).

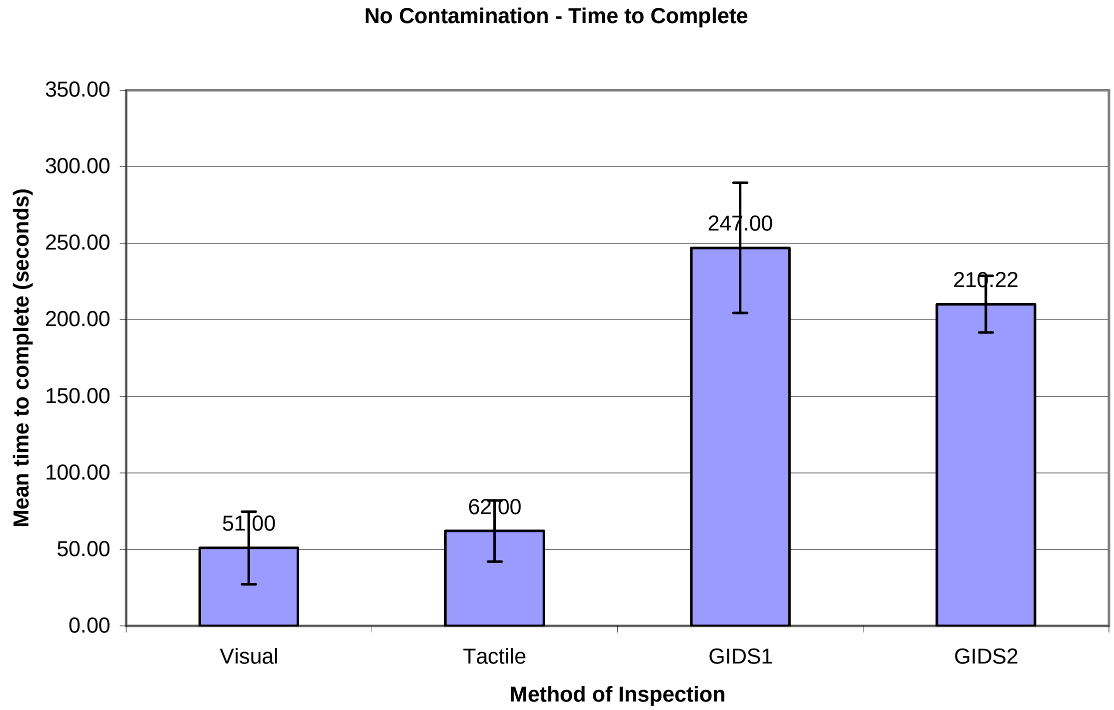

Figure 22. Mean Time to Complete the No Contamination inspection for each method of inspection.

Results of the significant pairwise comparisons using the LSD method are shown in Table 11. Results revealed that the Visual inspection took significantly less time than the Tactile method (*M* = 51.00, *SD* = 23.72 seconds vs. *M* = 62.00, *SD* = 20.06 seconds), GIDS1 method (*M* = 51.00, *SD* = 23.72 seconds vs *M* = 247.00, *SD* = 18.58 seconds) and GIDS2 method (*M* = 51.00, *SD* = 23.72 seconds vs. *M* = 210.22, *SD* = 105.78 seconds). The Tactile method took significantly less time than the GIDS1 method (*M* = 62.00, *SD* = 20.06 vs. *M* = 247.00, *SD* = 18.58 seconds) as well as GIDS2 method (*M* = 62.00, *SD* = 20.06 vs. *M* = 51.00, *SD* = 23.72 seconds).

Table 11. Pairwise comparison p values for Time to Complete the No Contamination inspection.

Pairwise Comparisons by Method of Inspection	***p* value**
Visual vs. Tactile	.016
Visual vs. GIDS1	.000
Visual vs. GIDS2	.003
Tactile vs. GIDS1	.000
Tactile vs. GIDS2	.003

11.3.1 Summary of Results

Visual inspection took the least amount of time (*M* = 51.00, SD = 23.72 seconds), followed by Tactile (*M* = 62.00, *SD* = 20.06 seconds), GIDS2 (*M* = 210.22, SD = 105.78 seconds) and GIDS1 methods (*M* = 247.00, *SD* = 18.58 seconds).

12. No Contamination Test Discussion

12.1 False Detections

The majority of false detections occurred for the GIDS2 condition (three false detections), followed by the Visual condition (two false detections), and lastly the Tactile condition (one false detection). No false detections occurred for the GIDS1 inspection.

12.2 Time to Complete Inspection

Time to complete the Visual, Tactile, GIDS1, or GIDS2 method of inspection was analyzed for the No Contamination condition. Visual inspections took the least amount of time, followed by Tactile inspections, GIDS2, and GIDS1. There was a significant difference for all of the pairwise comparisons except for the GIDS1 versus GIDS2 comparison.

These results are consistent with both the High and Low Contamination tests giving further strength to the data. However, it should again be noted that although general comparisons were made visual and GIDS inspections were not conducted as they would be in the field. Only a portion of the actual visual inspection was conducted and the GIDS systems, once in production form, may or may not be required to move down the wing or require a scan of the wing.

13. No Contamination Test Conclusions

The GIDS1 inspection resulted in the fewest amount of false alarms. GIDS2 has the highest false alarm rate for this test, followed by the Visual and Tactile methods.

Time to complete an inspection data was consistent with the previous tests. Again, Visual inspections took the least amount of time followed by Tactile, GIDS2, and GIDS1.

14. General Test Results

This section includes results that were collapsed among all test scenarios or should be considered collectively.

14.1 Objective Data

14.1.1 Manufacturer Test Results

As supplemental data, a representative from each GIDS manufacturer was asked to perform an inspection prior to starting data collection runs with the deicers. They completed an inspection in the same fashion as the deicers prior to all High Contamination, Low Contamination, and No Contamination tests. It is recognized that the data resulting from these sessions is compromised as the manufacturer representatives had access to the test plan and input regarding test design. The data was strictly meant to offer insight into whether training and familiarity with the systems might play a role in performance. It should be noted that although the GIDS manufacturers had access to the test plan, and therefore, the test diagrams prior to the test, it is unlikely that they remembered the exact placement of all of the patches for tests with contamination.

Data was analyzed by scoring accuracy data for the representatives and calculating descriptive statistics. Results showed that the manufacturer representative from the GIDS1 group found more ice patches than did the representative from the GIDS2 group. The High Contamination data is summarized in Figure 23 for each day. For both the low and No Contamination condition, both groups found the maximum number of ice patches (3 and 0 respectively) and had no false detections.

We also compared GIDS manufacturer results to deicer results in order to ascertain whether experience and training with the system might influence results. The GIDS1 manufacturer found all 12 patches on the wing for all three High Contamination runs although not all of the deicers did. This suggests that training and experience may play a role in using the equipment. The GIDS2 manufacturer representatives were unable to locate all of the patches for the High Contamination runs suggesting that the equipment itself was not detecting the patches and training is not necessarily a factor in its ability to detect ice.

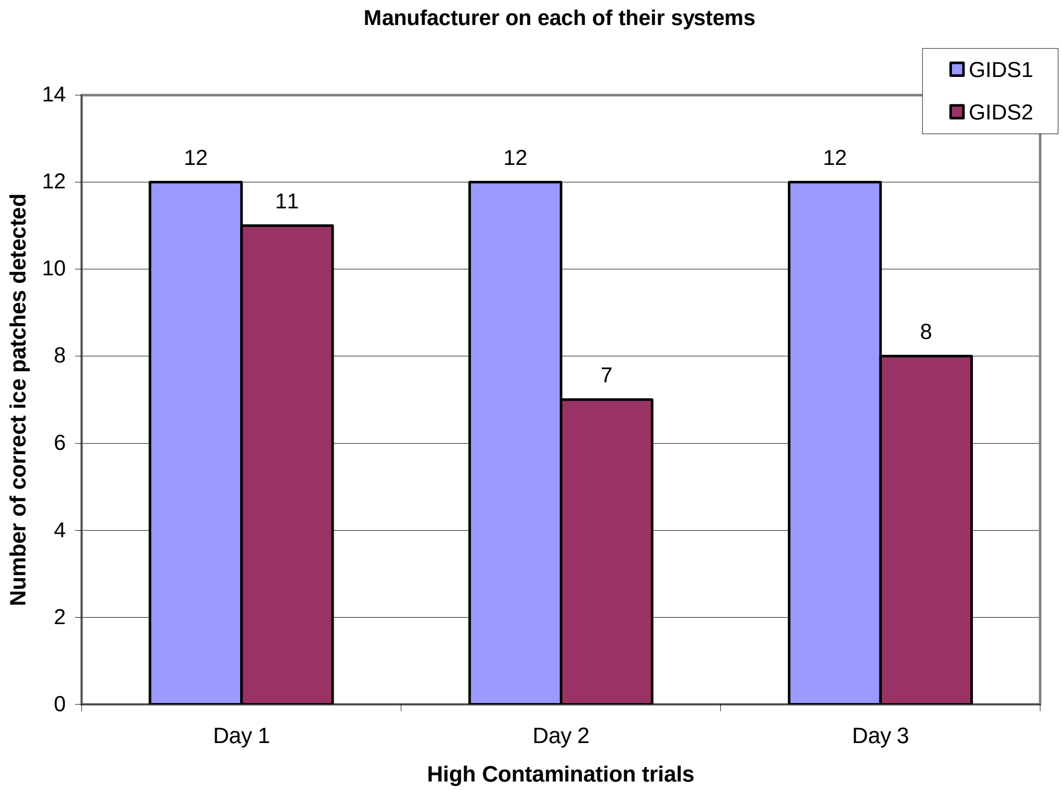

Figure 23. Number of patches correctly detected by manufacturers for the High Contamination Trials.

14.1.2 Description of movement on scissor lift

All deicers started their visual inspections at the lowest height on the scissor lift. They were permitted to move the lift vertically during the inspections if they chose to do so. We recorded the number of times each deicer moved vertically from their starting position, along with the height of each stop. The following section is a short description of their vertical movement during the visual tests.

The lowest height for the scissor lift, and the height at which all deicers began their inspection, was 54" from the floor. Their eye heights ranged from 63.5" to 66", with the average height being 65.7". The deicers moved the lift from their starting position at least once during 11 of the 27 visual tests; one deicer moved the lift twice for one run. The average height for the first lift was 74.2"and 81" for the second height. The movement range from the 54" start was between 60" and 81". Four of the nine deicers never moved the lift for any of their visual runs.

14.1.3 Re-deice data

We asked the deicers if they would re-deice the aircraft after each portion of an inspection (Visual, Tactile, GIDS1, and GIDS2). The data was designed to get an idea of how often deicers believed there was ice when there was none and would unnecessarily deice the aircraft (classified as a false positive) and how often they would not deice when it was necessary to do so (classified as a false negative).

Out of a total of 106 valid runs (Visual, Tactile, GIDS1, and GIDS2) there were a total of five false positives (4.7% of runs) and two false negatives (1.9% of runs). Of the five false positives, one was Visual, one was Tactile, and three were GIDS2. Of the two false negatives, one was the result of a Tactile inspection, the other a GIDS2 run.

The most interesting observation resulting from the data was that in six separate incidences three deicers found ice but reported they would not deice the aircraft. One deicer reported it three times, another two times, and one deicer reported they would not re-deice despite finding ice once.

14.2 Subjective Data

Subjective data was collected from deicers throughout the study in the form of workload ratings, questionnaires, and verbal comments. Table 12 lists the subjective data collected throughout the experiments. The resulting data was analyzed as appropriate and the results of the data are summarized in the following sections.

Table 12. Subjective Data

Data Type	Data Capture	Purpose
Background questionnaire	Before arriving for the study	Collect demographic information and inquire about health conditions that may disqualify them from the study
During the trial interview	Throughout each trial	Collect information concerning presence of ice, charting of location of ice, and whether deicing would be necessary based on simulated inspection
Post trial debrief	After each trial	Discuss interesting events and critical information regarding the presence of ice
NASA TLX	After each trial	Gather workload ratings
Post-test questionnaire	At the end of the study	Collect general information such as study fidelity
Post-test debrief	At the end of the study	Discuss use of GIDS for ice detection

14.2.1 Motivation

The TAs collected data on deicer motivation through several channels. Motivation was of particular concern in this study because of the cold environment and long waits between trials.

Vroom (1964) writes that motivation may be defined as intra- and inter-individual variability in behavior not due solely to individual differences in behavior or overwhelming environmental demands that coerce or force action (as cited in Kanfer 1990). There are three key components of motivational outcomes: direction, intensity, and persistence in effort (Kanfer, 1990). We kept detailed notes throughout the experiment so that we knew that our results were not confounded with changes in motivation. For example, for direction we noted whether deicers showed up on time, returned from breaks on time, and showed a willingness to participate. Other behaviors indicating a desire or lack of desire to participate were also noted. For intensity, we looked for subjective differences in workload using the NASA Task Load Index (TLX; see Appendix J; Users Manual Vol. 1, n.d.). For persistence of performance, we analyzed the data for consistency in performance over the course of the experiment. Motivational analysis was conducted independently of test results. This analysis was simply a way to identify any results that may have been confounded by motivational issues.

14.2.1.1 Direction

For direction, we noted aspects of deicer behavior that may have indicated that deicers lacked direction. No such evidence existed. Notes indicated that deicers showed up on time throughout the study, returned from breaks on time, and showed a willingness to participate. In addition, deicers ushered themselves to each testing station and interview session with little guidance from test personnel.

14.2.1.2 Intensity

For intensity, we looked for subjective differences in workload using the NASA Task Load Index. Total workload was calculated using the sum of the product of each subjective rating for each dimension of workload (e.g., effort, performance, frustration, etc.) and the weights assigned to each dimension by the deicer. Repeated measures ANOVAs were conducted for each test (High Contamination, Low Contamination, and No Contamination) to assure that workload was stable across groups. If mean workload was significantly different for each group across conditions, it would suggest that the intensity devoted to the task across days may have been different.

Repeated measures ANOVAs revealed that the differences in workload across groups for each condition were not statistically significant for differences for the High, Low or No Contamination test. As depicted in Figure 24, Figure 25, and Figure 26 the mean workload for each condition indicated that the workload was relatively stable across groups and there was no evidence that group differences existed for workload in any of the tests. Workload ebbs and flows were considered to be random variations.

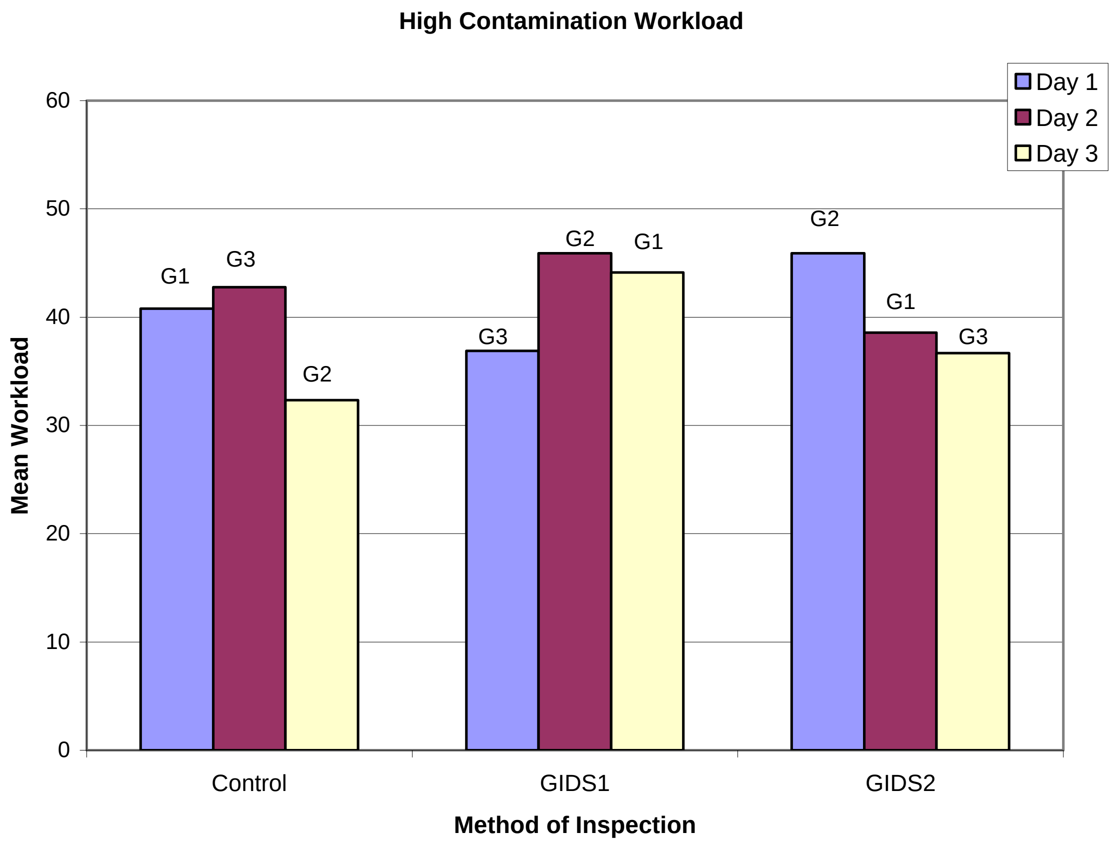

Figure 24. Mean workload for each group as a function of condition for the High Contamination Test.

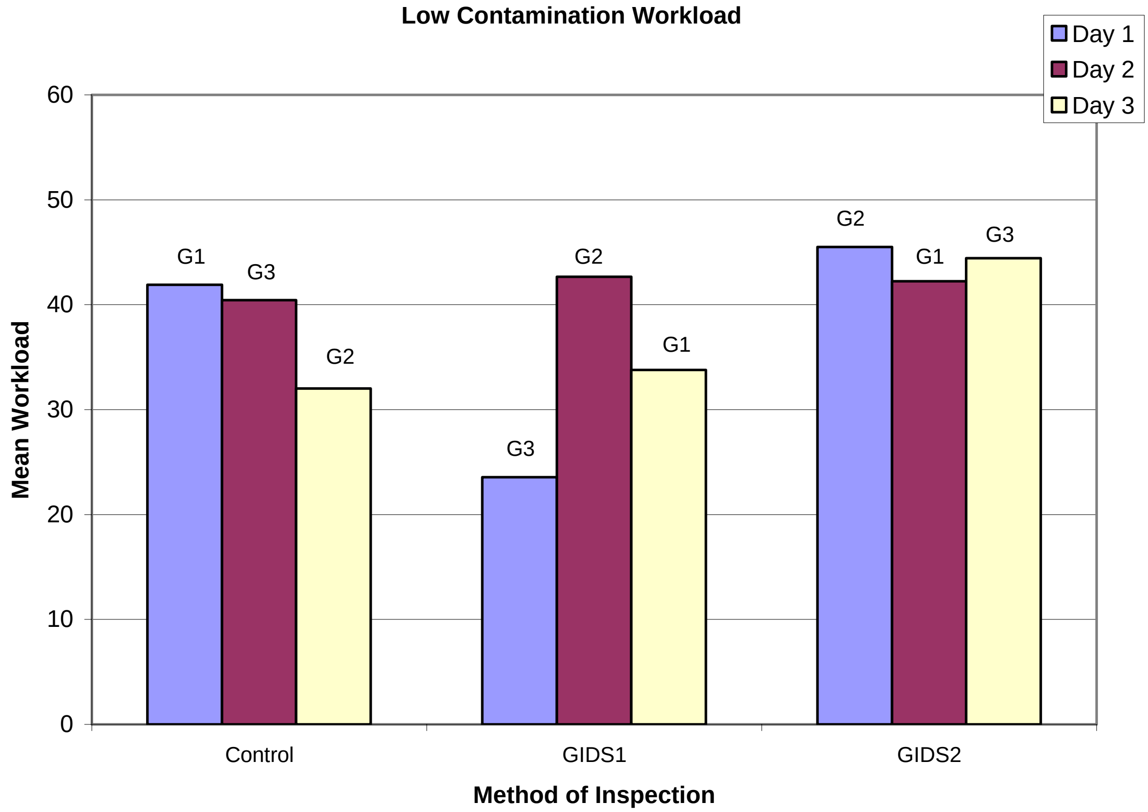

Figure 25. Mean workload for each group as a function of condition for the Low Contamination Test.

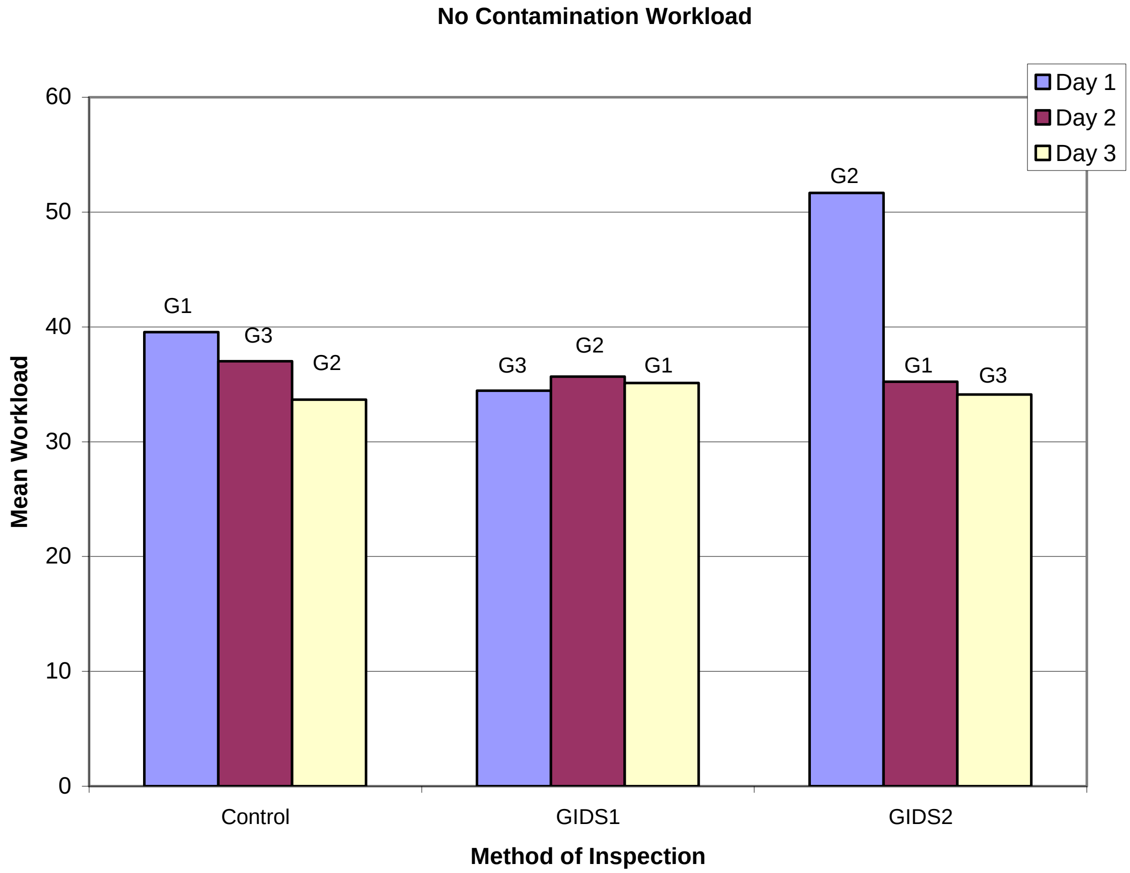

Figure 26. Mean workload for each group as a function of condition for the No Contamination Test.

14.2.1.3 Persistence

For persistence of performance, we examined the mean of correct responses across days (or groups) for each method of inspection. Stable performance across groups would suggest that deicer persistence was constant throughout the three days of testing.

To make sure that performance for each of the four methods of inspection did not vary significantly from day to day, statistical t-tests were conducted. This analysis was performed for the High and Low Contamination tests only because there is no correct detection data to examine for the No Contamination test. Each of the trial days consisted of different subject groups, for example, day one Control group consisted of deicers 1, 2, and 3. Day two consisted of deicers 7, 8 and 9, and day 3 consisted of deicers 4, 5, and 6. This test analyzed whether or not the groups were statistically different from each other for each of the four methods of inspection. Significance was set at the .01 level since there are only three deicers for each of the three groups/days.

The mean number of correct detections for each day across conditions remained relatively stable for the High Contamination test (see Figure 27). However, there was a statistically significant difference in performance for the GIDS2 condition between the Day 1 and Day 2 groups (M = 7, SD = 0 vs. M = 4.3, SD = .58). It is unclear whether this difference is due to group performance for GIDS2 (the two group's scores were exactly the same for the GIDS2 Low Contamination test) or whether motivational differences for persistence existed between the groups for that particular run. It is clear, however, that no other evidence existed that motivation was a confounding factor in the test.

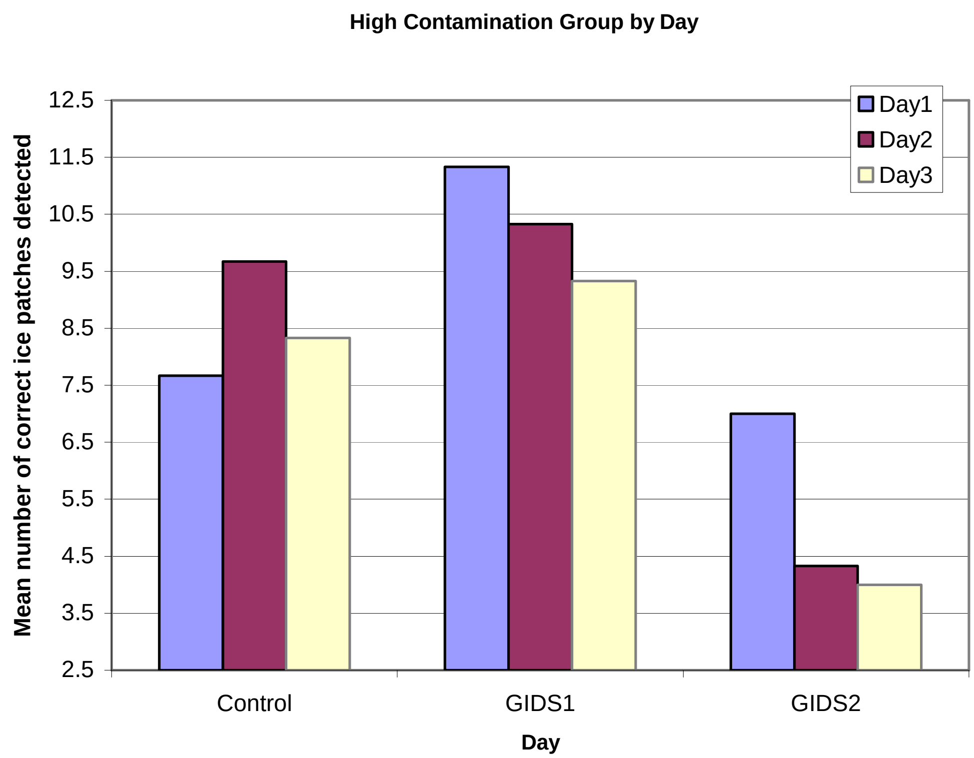

Figure 27. Groups' mean of correct responses for day across conditions.

The Low Contamination data suggests that no statistically significant differences exist between any of the groups for each of the four methods of inspection. Figure 28 plots the mean number of correct patches detected by day across conditions. The stability in performance suggests that persistence in performance was not an issue and that differences were due to random variation in performance.

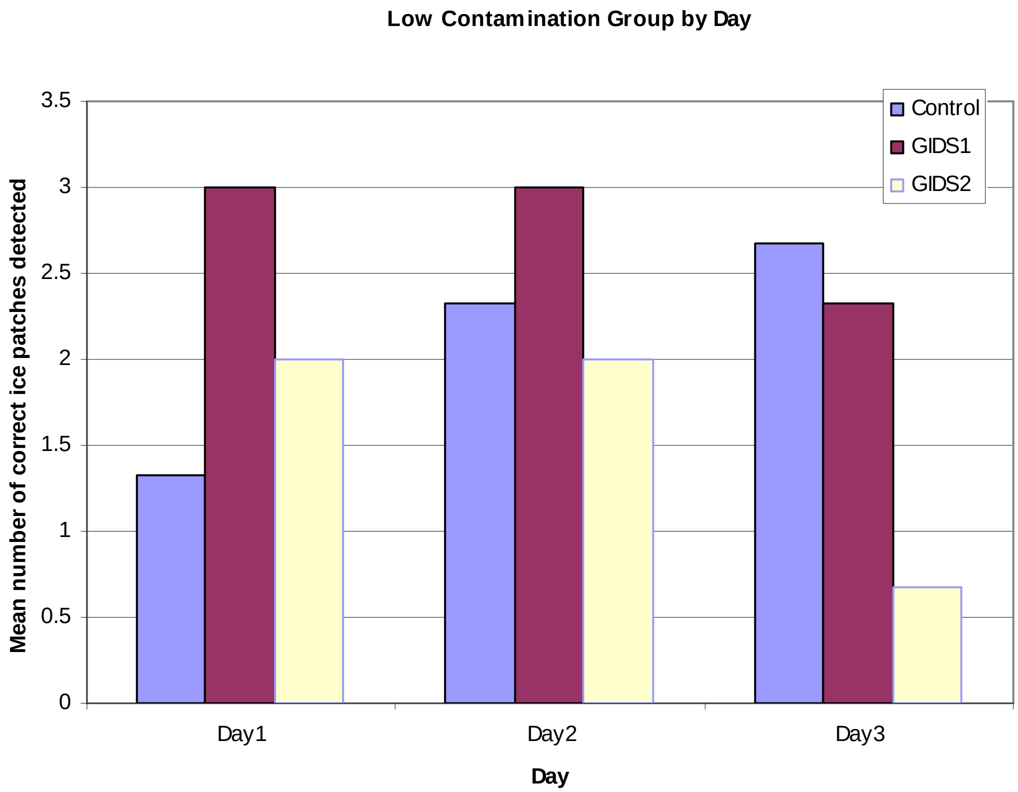

Figure 28. Groups' mean correct responses for day across conditions.

14.2.2 <u>Questionnaire Data</u>

Questionnaires were distributed to participating deicers to elicit opinions about their experience with each condition as well as the overall study. A summary of responses from the deicers are presented in the following sections. Debrief sessions and comments on questionnaires were summarized and included where appropriate, with particular emphasis on interesting or recurring themes.

The Post Test Questionnaire was designed using 7-point Likert scales. Therefore, all rankings ranged from either -3 to 3 (with 0 acting as a neutral point) or 1 through 7. Anchors varied according to the accompanying statement or question. Questionnaires were administered in sections by condition (Visual and Tactile, GIDS1, and GIDS2). Deicers completed the appropriate questionnaire at the end of each day. A realism questionnaire was administered on the last day of the study when all tests were complete. Deicers provided feedback on whether environmental factors, wing and ice characteristics, or physiological effects had any affect on their performance. GIDS 1 and 2 questionnaires gathered deicer impressions of the systems in terms of safety and confidence in them. Deicers were given an opportunity to supplement or revise their answers on the last day after reviewing their test scores.

Data analysis for the questionnaires consisted of deriving descriptive statistics for each individual question. For the purpose of reporting responses, the overall median (*Md*) scores were used to describe the data. The median score is the most appropriate measure of central tendency when using ordinal data or when scores are not normally distributed. The median is the value such that one half of the observations fall above and one half fall below the value. When there are even numbers of observations, no unique center value exists, so the mean of the two middle observations is taken as the median value.

In the following sections, the responses for each section of the questionnaire are summarized.

14.2.2.1 <u>Visual and Tactile Inspection Condition</u>

Deicers reported that noise, temperature, wind, and time pressure did not affect their ability to detect ice in the chamber during their visual and tactile inspections (median score of 0, or *no effect,* on a scale of -3 = *Made it Extremely Difficult* to 3 = *Made it Extremely Easy*). Wing color, fluid, ice thickness, ice roughness, and ice edge had a slight effect on their ability to find ice (*Md* = -1 on a -3 = *Made it Extremely Difficult* to 3 = *Made it Extremely Easy* scale). Lighting, viewing angle, and viewing distance had the most effect on their ability to find ice (median = -2 on a -3 = *Made it Extremely Difficult* to 3 = *Made it Extremely Easy* scale). The score for the latter was consistent with feedback from several deicers who said that they experienced some difficulty detecting ice because of their inability to move during the visual portion of the inspections and because some of the equipment they normally use was not available to them (e.g. tactile wands and flashlights).

Fatigue and boredom reportedly did not affect deicer performance although deicers did report that they were somewhat bored. The median answer for both their level of fatigue and boredom was 3 on a scale of 1 to 7; *Not Bored at All* to *Extremely Bored*. When asked how these factors affected their performance the median response was 1 or *No Effect* (7 corresponded to *Greatly Decreased Performance*).

Several deicers remarked that they believed the study design made inspections more difficult. The most common reason cited for the difficulty was the lack of movement during the visual portion of the test. A couple of deicers commented that they had difficulty seeing the root of the wing from the visual position. Lack of extra equipment that was normally available to them in the field, including spotlights and a tactile wand, was also cited as a reason for the difficulty. It should be noted that the equipment and instruments that assist in ice detection (e.g. tactile wands and spotlights) are not standard for every facility and all facilities do not necessarily use the same methods and procedures for detection. Several dayshift deicers remarked that they had more difficulty because they were not used to "nighttime" conditions.

14.2.2.2 <u>GIDS1 Inspections</u>

Temperature, noise, wind, and time pressure reportedly had no effect on the deicers' ability to find ice while performing their GIDS 1 inspections. The median score was 0, or *No Effect*, when asked if any of these environmental factors affected their ability to find ice (-3 = *Made it Extremely Difficult*, 3 = *Made It Extremely Easy*).

Deicers did report experiencing some fatigue (*Md* = 3 on a scale of 1 = *Not Fatigued At All* to 7 = *Extremely Fatigued*) and boredom (*Md* = 4 on scale of 1 = *Not Bored At All* to 7 = *Extremely*

Bored) but claimed that neither of these had an effect on their performance (*Md* = 1 or *No Effect*).

They reported that they "*Definitely*" did feel adequately trained on the GIDS1 device (*Md*= 3 on a scale of -3 = *Definitely Not* to 3 = *Definitely*) suggesting that lack of training should not have affected their impressions of the system.

14.2.2.2.1 Visual inspections compared to GIDS1

Deicers believed that GIDS1 inspections might have been slightly better than visual inspections (*Md* of 1 on a scale where -3 equaled *Absolutely Worse* and 3 equaled *Absolutely Better*). They indicated that safety, both of the airplane and their personal safety, would not be significantly affected by replacing visual inspections with GIDS1, but may make a slight improvement (*Md* = 1 where -3 was *Absolutely More Dangerous* and 3 was *Absolutely Safer*). A median of 0 indicated that there "*would be no difference*" in response to whether they would recommend replacing current visual inspections with GIDS 1 inspection (-3 = *Definitely Not*, 3 = *Definitely*).

14.2.2.2.2 Tactile inspections compared to GIDS 1

Deicer's indicated that there would be no difference between the GIDS1 and tactile inspections for finding ice (*Md*=0 on a scale where -3 was *Absolutely Worse* to 3 or *Absolutely Better*). They indicated that they believed that GIDS1 would be slightly safer than a tactile inspection in terms of their personal safety (*Md* = 1) but would not affect the safety of the airplane (*Md*=0 where the scale was -3 = *Absolutely More Dangerous* and 3 = *Absolutely Safer).* They indicated a median response of 0 (-3 = *Definitely Not*, 3 = *Definitely*), or "*there would be no difference*", when asked if they would recommend replacing current tactile inspections with GIDS1.

They reported that they were fairly confident in the accuracy of the GIDS1 inspection by indicating a median of 5 on scale of 1 = *Not Confident At All* to 7 = *Extremely Confident*.

14.2.2.2.3 Use of GIDS Devices Prior to the Study

Three of the deicers had used a GIDS system during the course of their employment; six had not. One deicer had used a version of GIDS1 during the course of his employment (although one deicer failed to indicate to which system he had been exposed prior to the test). When asked how the GIDS1 device compared to the one they used in the field, two deicers remarked that it was better; the last said it performed the same.

14.2.2.2.4 Open Ended Feedback

When asked how else the GIDS device might be used in the field the deicers said it could be used to detect ice on the deicing pad, runways, and taxiways. One deicer suggested it could be used to detect fuselage and leading edge ice. Deicers also remarked that it could be used in combination with conventional methods (Visual/Tactile inspections).

14.2.2.3 GIDS2 Inspections

Deicers reported that temperature, noise, wind, and time pressure had no effect on their ability to detect ice during their GIDS 2 inspections by indicating a median response of 0, or had *no effect* (-3 = *Made It Extremely Difficult* and 3 = *Made It Extremely Easy*). They reported some fatigue (*Md* = 2 on a scale of 1 = *Not Fatigued At All* to 7 = *Extremely Fatigued*) and boredom (*Md* = 4 on scale of 1 = *Not Bored At All* to 7 = *Extremely Bored*) but claimed that both factors had very little effect on their performance (*Md*=2 on a scale where 1 = *No Effect* and 7 = *Greatly Decreased Performance*).

To a large degree deicers felt adequately trained in GIDS 2 (*Md*= 2 on a scale of -3 = *Definitely Not* to 3 = *Definitely*). One deicer commented that they were slightly unsure how to identify possible false positives when asked why they may have felt less than adequately trained.

14.2.2.3.1 Visual inspections compared to GIDS2

Deicers believed that the GIDS2 inspections might be slightly better than visual inspections (*Md* = 1 on a scale where -3 = *Absolutely Worse* and 3 = *Absolutely Better*). They did not believe that safety, either of the airplane and their personal safety, would be significantly affected by replacing visual inspections with GIDS2 (*Md* = 1 on a scale where -3 = *Absolutely More Dangerous* and 3 = *Absolutely Safer*). In response to whether they would recommend replacing current visual inspections with a GIDS2 inspection the median response was 0 or *"no difference"* (-3 = *Definitely Not* and 3 = *Definitely*)

14.2.2.3.2 Tactile inspections compared to GIDS2

Deicer's indicated that there would be no difference between the GIDS2 and tactile inspections for finding ice (*Md* = 0 on a scale where -3 was *Absolutely Worse* and 3 was *Absolutely Better*). They indicated that they believed that GIDS2 would be slightly safer than a tactile inspection in terms of their personal safety (*Md* = 1) but would not affect the safety of the airplane (*Md* = 0 on a scale where -3 = *Absolutely More Dangerous* and 3 = *Absolutely Safer*). They indicated a median response of 1 (-3 = *Definitely Not*, 3 = *Definitely*), or slightly positive response, when asked if they would recommend replacing current tactile inspections with GIDS2.

Deicers reported that they were somewhat confident in the accuracy of the GIDS2 inspections by indicating a median of 4 on scale of 1 = *Not Confident At All* to 7 = *Extremely Confident*.

14.2.2.3.3 Use of GIDS Devices Prior to the Study

Three of the deicers had used a GIDS system during the course of their employment; six had not. Two deicers had used a version of GIDS2 during the course of his employment (the remaining deicer failed to indicate to which system he had been exposed prior to the test). When asked how the GIDS2 device compared to the one they used in the field, two deicers remarked that it was slightly better than the version they had used prior but was still not good enough. The remaining deicer said simply that it performed the "same" but did not indicate whether this was good or bad.

14.2.2.3.4 Open Ended Feedback

When asked how else the GIDS device might be used in the field, the deicers recommended that it be used to inspect for ice on such entities as the deicing pad, runways, taxiways, and critical areas of the aircraft. Deicers also remarked that it could be used in combination with conventional methods (visual/tactile inspections).

Two of the nine deicers commented that they did not feel confident in the GIDS2 system and would not trust the system unless major improvements were made. Several deicers also noted that the delay in receiving the image was excessive.

14.2.2.4 Realism

For both the High and Low Contamination tests, deicers' indicated a median of 4 when asked how the inspection procedures for the study compared to real world post deicing procedures (1= *Not Realistic At All,* 7 = *Extremely Realistic*). The most common reason cited for the lack of realism were deicers' inability to move the platform down the wing as they would in the field. Deicers also commented both in writing and during debrief sessions that they were not allowed the opportunity to use some of the equipment they would normally use in the field (such as the tactile wand and a spot light).

For both the High and Low Contamination wings the deicers' rated the overall wing condition as compared to real world post deicing conditions as a 4 on a scale where 1 = *Not Realistic At All* and 7 = *Extremely Realistic*. The realism for the ice samples on the wing, compared to residual ice seen post deicing in the field, for the High Contamination wing rated a 5 while the Low Contamination wing study rated a 4 (1 = *Not Realistic At All* to 7 = *Extremely Realistic*). It is somewhat surprising that the High Contamination wing received higher deicer ratings (although slight) since it is unlikely that 12 patches would remain on the wing post-deicing. The reasons indicated for lower realism scores in this category were the difficulty level of the lighting (night conditions for those who work in the daytime) and lack of movement. It was also noted that the shape of the ice patches was not very realistic because it would be unlikely that residual ice would be a perfect circle.

15. General Discussion

The goal of this study was to investigate whether GIDS systems are as good as, or better, at detecting residual ice than current inspection methods (visual and tactile) post deicing. To meet the objective of the study three separate post deicing scenarios were presented to deicers in one of three conditions: the current method (Visual inspections and Tactile inspections), the GIDS1 system, and the GIDS2 system. The scenarios presented three wing conditions with different amounts of contamination to the deicers each day for three days. One scenario was conducted with 12 ice patches on the wing (High Contamination), the second with three ice patches on the wing (Low Contamination), and the last with a clean wing (No Contamination). Accuracy data (number of patches correctly detected), false detections data (number of patches found that were not there), and times to complete an inspection were collected and analyzed for each test and condition. The data gathered consistently indicated that overall GIDS1 was superior to the other methods of inspection in terms of accuracy, false detections, and stability of performance.

GIDS1 was able to detect all patch sizes and thicknesses with the most accuracy and with little variation as a function of patch size and thickness while the other methods' accuracy improved as a function of patch size and thickness. In addition, the GIDS1 manufacturer representative runs results collected in the study suggest that, with time and experience, performance could further improve.

15.1 Accuracy

Accuracy evaluations were conducted through two different tests: the High Contamination and Low Contamination tests. Analyses from both tests were consistent, in that GIDS1 detected more patches than the other methods for both tests. GIDS1 was also superior to the other methods of inspection in terms of stability in performance, as it was able to detect all patch sizes and thicknesses with the most accuracy. Visual, Tactile, and GIDS2 methods had lower accuracy rates for the thin patches (.3-.5 mm) in particular. Performance did appear to improve as patch size and thickness increased for the Visual, Tactile, and GIDS2 conditions. In addition, GIDS manufacturers conducted inspections prior to deicer runs for the purpose of collecting supplemental data. The resulting data from these inspections indicate that with time and experience, GIDS1 performance could further improve.

Beyond GIDS1, analysis indicated that the Tactile inspections found more patches than the Visual inspections or GIDS2 inspections for the High and Low Contamination tests, although the difference was not always statistically significant. The Tactile test simulated in this study was conducted on a wing that was relatively low to the ground. A higher wing may have further limited the reach of the operator, introducing the possibility that detection may have decreased. Visual inspections were similar to GIDS2 inspections in terms of accuracy. Visual and GIDS2 tests results were comparable for the Low Contamination test but the GIDS2 systems performed slightly better for the High Contamination test. However, it should be noted that visual inspection performance accounted for only a portion of an actual visual inspection since they were conducted from one location.

Despite the fact that statistical significance was not always reached for the accuracy data, it is important to note that the consistent overall differences, as well as significant differences, may constitute operational significance. The reliability (consistency) of the data across tests suggests that the potential for operational improvements may exist with use of the GIDS1 system.

15.2 Time to Complete Inspection

GIDS1 was poorest in terms of time to complete inspections compared to the other methods investigated across all three tests. Visual inspections took the least amount of time to complete followed by the Tactile inspection and GIDS2. However, these results should be regarded with caution, as the time to complete inspection data does not necessarily reflect the true inspection times. Due to space constraints in the chamber, visual and GIDS inspections were limited to one inspection point. In the field, deicers would normally move down the wing in a basket to conduct their visual inspections and the GIDS would move with them. Therefore, visual inspection times for the test represent only a portion of the actual process, artificially deflating completion times. In addition, GIDS time to complete data may be artificially inflated because

GIDS inspections included time that deicers spent diagramming contamination and scanning the wing using a joystick, which they may not do in an operational setting.

15.3 Subjective Feedback

15.3.1 Motivation

We monitored motivation by collecting data for three key motivational components: direction, intensity, and persistence in effort. Motivation was of concern to the test team due to the cold environment and long waits between the tests. No evidence existed that the deicers lacked direction or intensity, but one difference was present for persistence in effort between Groups 1 and 2 for the GIDS2 High Contamination test. It is unclear whether this difference is due to group performance differences or whether motivational differences existed between the groups for that particular test. It is clear, however, that no other evidence existed that motivation was a confounding factor in the test.

15.3.2 Questionnaire Results

No statistically significant information resulted from the Questionnaires administered to collect subjective feedback. Deicers provided predominantly neutral responses in terms of their attitudes, confidence, and perceived safety of the GIDS systems. They did report, however, that no physiological or environment factors interfered with the results. Some deicers did comment that they were somewhat frustrated with the restricted movement required during the visual test. Several deicers believed that the limited movement restricted their ability to see the entire wing and, therefore, negatively affected their visual performance. Several deicers also commented that their performance might have improved if given the opportunity to use some of the equipment available to them in the field (e.g. the use of illumination as a tool or tactile wands). The lack of movement and equipment also resulted in somewhat lower realism scores for inspection procedures.

16. Overall Conclusions

The results indicate that overall the GIDS1 inspection method is superior to Visual, Tactile, and GIDS2 inspection methods. The results from the study indicate that a technology currently exists that is as good as or better than the current human detection system. According to the results from this study, there is strong evidence that the GIDS1 system should be further evaluated to ensure that detection capability is stable across a variety of conditions. Furthermore, as it becomes appropriate the GIDS1 system should undergo an interface and design evaluation with SMEs providing input regarding system design prior to operational use in the field.

Study results indicate that GIDS2 should not be considered for field implementation in its current configuration. Study results indicate that in its current technological state, the systems detection capability was on par with a limited visual inspection, but not as effective as a tactile inspection. Technical improvements and further testing would have to be conducted before a recommendation for further consideration of this device in a field setting could be made.

Test results suggest that deicers may not meet the current standard of a 100% clean wing, 100%

of the time (although we do recognize that the visual inspections procedures used in this study were not as comprehensive as they are in the field). The visual inspection procedures used in this study did not account for movement, illumination as tool, or tools available to deicers in the field. However, conditions in the field will sometimes be much more difficult than the conditions used in the study. Further testing with realistic and comprehensive visual and tactile inspections could be performed if this type of field-testing is to be pursued.

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APPENDIX A

COMPARISON STUDY BACKGROUND FORM

Comparison Experiment

Background Questionnaire

Please fill out this questionnaire and return it to the test administrator.

Today's date *MM/DD/YYYY*
Participant code
Occupation

1	Date of birth (*MM/DD/YYYY*)	**1**	/ /
2	Gender (check one)	**2**	☐ Male ☐ Female
3	How long have you worked deicing aircraft?	**3**	years months
4	Do you suffer from any form of color blindness?	**4**	☐ Yes ☐ No
5	Do you have normal or corrected to normal vision (20/20)?	**5**	☐ Yes ☐ No
6	Please check all that apply to you.	**6**	☐ Eyeglasses ☐ Contact lenses ☐ Corrective surgery
7	Please indicate whether you are wearing any of the following.	**7**	☐ Eyeglasses ☐ Contact lenses
8	Have you ever received medical attention for any of the following injuries/illnesses?	**8**	☐ Frost Bite[4] ☐ Hypothermia[5] ☐ Other
9	If you checked a box in Question 8, please indicate when you received medical attention.	**9**	/ / / /
10	Did you fully recover from all of the injuries/illnesses?	**10**	☐ Yes ☐ No

[4] "Frostbite refers to the freezing of body tissue (usually skin), that results in loss of feeling and color in the tissue" (Brooks, 2001).
[5] "Hypothermia is a condition of body chilling that occurs when the body looses heat faster than heat can be produced by muscle contractions, metabolism, and shivering" (Hess, 2004).

11 Please indicate whether you have any of the following health conditions or any other health condition that may predispose you to cold related illnesses.

11	☐ Diabetes
	☐ Hypertension
	☐ Cardiovascular
	Disease
	☐ Other

Thank You.
Please return this questionnaire to the Test Administrator.

Expérience de détection

Données personnelles

Veuillez répondre au questionnaire et le remettre à l'administrateur de tests.

Date du jour *MM/JJ/AAAA*
Code de participant
Profession

1	Date de naissance (*MM/JJ/AAAA*)	**1** / /
2	Sexe (cochez une case)	**2** ☐ Homme ☐ Femme
3	Depuis combien de temps travaillez-vous au dégivrage des avions?	**3** ans mois
4	Souffrez-vous d'un trouble de la vision des couleurs (ex: daltonisme)?	**4** ☐ Oui ☐ Non
5	Avez-vous une vision normale ou corrigée de 20/20?	**5** ☐ Oui ☐ Non
6	Veuillez cocher toutes les réponses qui vous concernent.	**6** ☐ Lunettes ☐ Verres de contact ☐ Chirurgie correctrice
7	Veuillez indiquer si vous portez l'une ou l'autre de ces corrections.	**7** ☐ Lunettes ☐ Verres de contact
8	Avez vous déjà été traité pour l'une ou l'autre de ces blessures/maladies?	**8** ☐ Gelure[6] ☐ Hypothermie[7] ☐ Autre
9	Si vous avez coché une case à la question 8, veuillez indiquer quand vous avez été traité.	**9** / / / /

[6] La gelure est la congélation de tissu organique (habituellement la peau) entraînant la perte de sensation et la décoloration du tissu (Brooks, 2001).

[7] L'hypothermie est une baisse générale de la température centrale du corps, qui survient lorsque la chaleur produite par la contraction des muscles, le métabolisme et le frissonnement n'arrive pas à compenser la chaleur perdue par l'organisme (Hess, 2004).

Données personnelles

10	Le cas échéant, êtes-vous complètement guéri de toute blessure/maladie?	**10**	☐ Oui ☐ Non
11	Veuillez indiquer si vous présentez l'un ou l'autre des problèmes de santé suivants, ou tout autre problème susceptible de vous prédisposer à des maladies reliées au froid.	**11**	☐ Diabète ☐ Hypertension ☐ Maladie cardiovasculaire ☐ Autre

Merci.
Veuillez remettre ce questionnaire à l'administrateur de tests.

APPENDIX B

PARTICIPATION CONSENT FORM

Participation Consent Form

To the Research Participant: Please read this consent form and the attached protocol and/or subject instructions carefully. Make sure all of your questions have been answered to your satisfaction before signing.

I AGREE TO PARTICIPATE IN THE STUDY *COMPARISON OF HUMAN ICE DETECTION CAPABILITIES AND GROUND ICE DETECTION SYSTEM PERFORMANCE UNDER POST-DEICING CONDITIONS* (HEREAFTER REFERRED TO AS THE *COMPARISON STUDY*). I UNDERSTAND THAT THE FEDERAL AVIATION ADMINISTRATION (FAA) OFFICE OF AVIATION RESEARCH SPONSORS THIS EXPERIMENT, THE FLIGHT SAFETY BRANCH (AJP-6350) IS THE PROJECT MANAGER, AND THAT THE FAA'S SIMULATION AND ANALYSIS GROUP (ACB-330) DIRECTS THIS EXPERIMENT.

Nature and Purpose:
The Comparison Study is intended to determine whether any benefit is gained by using Ground Ice Detection Systems (GIDS). Deicers will inspect a wing under post-deicing conditions. The wing may or may not be contaminated with ice. One group of deicers will use current visual and tactile inspection techniques, the second group will use a system developed by “Manufacturer A,” and the third group will use a system developed by “Manufacturer B.” The purpose of the study is to compare ice detection performance using current methods and using GIDS.

Experimental Procedures:
Nine deicers from Aero Mag and Globe Ground will participate in this study over a three day period. An RJ wing will be placed inside of a cold chamber and displayed as a wing would post deicing. A deicer from each group will inspect a wing that may or may not be contaminated with ice. A deicer from the first group will inspect the wing using current visual and tactile ice detection procedures. A deicer from the second group will inspect the same wing using a GIDS system developed by Manufacturer A. Finally, a deicer from the third group will inspect the wing using a GIDS system developed by Manufacturer B. During each inspection, deicers will indicate on a diagram the location where they believe that the wing was contaminated with ice.

Discomforts and Risks:
The discomforts and risks anticipated in this experiment are not greater than those ordinarily encountered by a deicer performing his or her job. The cold chamber will be approximately -5° C with a slight wind. There is little danger of freezing to exposed flesh and cold related illnesses if proper precautions are exercised.

It is my responsibility to notify the TA if I have health conditions that predispose me to cold related illnesses. Predisposing health conditions include but are not limited to cardiovascular disease, diabetes, and hypertension.

It is my responsibility to wear proper clothing including a hat and gloves.

I will alert the TA if I am feeling any discomfort or require a break. Frequent, lengthy breaks in warm dry rooms are scheduled into the experiment to allow my body to warm up, but I will not hesitate to request a break at any time.

Benefits:
I understand that the benefit to me is the opportunity to participate in research that examines current human ice detection performance and systems that may benefit ice detection in terms of safety and performance.

Participant Responsibilities:
During the study, it will be my responsibility to check the wing for ice and to regard the inspection as if it were being performed on an actual aircraft. I will answer any questions asked during the study to the best of my abilities. I will not discuss the content of the study with anyone until its formal completion. I will complete a background questionnaire, a post-run questionnaire at the end of each run, and a post-study questionnaire at the end of all the runs. I will participate in debriefs at the end of each run, and at the completion of the full study.

Participant's Assurances:
I understand that my participation in this experiment is completely voluntary. The Principal Investigator will adequately answer any and all questions I have about this experiment, my participation, and the procedures involved. I understand that if new findings develop during the course of this research that may relate to my decision to participate, I will be informed.

I have not given up any of my legal rights or released any individual or institution from liability for negligence.

I understand that records of this experiment are strictly confidential, and that I will not be identifiable by name or description in any reports or publications about this study. Video and audio recordings are for use within the William J. Hughes FAA Technical Center (WJHTC) only. Any of the materials that may identify me as a participant cannot be used for purposes other than internal to the WJHTC without my written permission.

I understand that I can withdraw from this study at any time without penalty or loss of benefits to which I may be entitled. I also understand that the researcher or sponsor of this study may terminate my participation if he or she feels this to be in my best interest.

If I have questions about this experiment or need to report any adverse effects from the research procedures I will contact Edmundo Sierra at (609) 485-7360.

I have read this participation form, I understand its contents, and I freely consent to participate in this study under the conditions described. I have received a copy of this participation form.

Signature of Research Participant: _______________Date: ____________

Research Director: ____________________________Date: ____________

Witness: _____________________________________Date: ____________

APPENDIX C

CLOTHING SUGGESTIONS

(English and French Versions)

Dear Participant,

Thank you for volunteering to participate in our experiment. We would like you to be as safe and comfortable as possible during your participation. For your safety and comfort, we are providing the following information.

The cold chamber in which you will participate will be -5° C, there will be a slight wind, and no precipitation. Even though you will receive a number of breaks, you will spend a significant amount of time in this cold environment.

We suggest the clothing listed in the table below. It was adapted from U.S. Army Field Manual 31-70 and lists some basic components of cold-dry conditions clothing for these conditions. Of course, you may also refer to your employer's guidelines and experience for adequate protection and comfort in these conditions.

Basic Components of Cold-Dry Clothing

Item	Name	Description
1	Undershirt	50 Cotton 50 Wool, Full Sleeve
2	Drawers	50 Cotton 50 Wool, Ankle Length
3	Socks	Wool Cushion Sole, Stretch Type
4	Suspenders Trousers	Scissor Back Type
5	Shirt	Wool, Nylon, Flannel
6	Trousers	Cotton Nylon, Wind Resistant Sateen
7	Liner Trousers	Nylon Quilted, 6.2 oz
8	Boot Insulated Cold Weather	Rubber w/release valve
9	Coat	Cotton and Nylon Wind Resistant Sateen, 8.5 oz
10	Liner Coat	Nylon Quilted, 6.2 oz
11	Parka	Cotton and Nylon Oxford w/o hood
12	Liner Parka Mans	Nylon Quilted 6.2 oz
13	Cap, Insulating, Helmet Liner	Cotton Nylon Oxford
14	Hood Winter	Cotton and Nylon Oxford
15	Glove Shells	Leather Black with Glove Inserts ; Wool and Nylon Knit

OPTIONAL CLOTHING in GRAY

It takes a couple of hours to clean and apply the ice to the wing that you will be inspecting. That means that you will have a lot of free time in between sessions. We suggest that you bring along something to do during that waiting period.

If you have any questions, please contact me at the number below. We look forward to seeing you!

Edmundo Sierra
Human Factors Engineer
(609) 485-7360

PLEASE KEEP THIS LETTER FOR YOUR RECORDS

Cher participant,

Merci de bien vouloir participer à notre expérience. Nous voulons que vous soyez le plus en sécurité et le plus confortable possible pendant l'expérience. Pour votre sécurité et votre confort, nous vous demandons de lire l'information qui suit.

La chambre froide dans laquelle sera menée l'expérience sera maintenue à -5° C, avec un vent léger et aucune précipitation. Même si vous aurez droit à des pauses, vous passerez beaucoup de temps dans ce milieu froid.

Nous vous suggérons de vous munir des vêtements énumérés dans le tableau ci-après. Cette liste, inspirée d'un manuel de l'armée américaine (U.S. Army Field Manual 31-70), comprend les éléments de base d'une tenue adaptée à un froid sec. Bien sûr, vous pouvez aussi vous fier aux directives de votre employeur et à votre expérience pour savoir quels vêtements porter pour être au chaud et confortable dans ces conditions.

Éléments de base d'une tenue pour froid sec

Article	Désignation	Description
1	Gilet de corps	50 % coton, 50 % laine, manches longues
2	Caleçon	50 % coton, 50 % laine, jambes longues
3	Chaussettes	En laine, à semelle matelassée, extensibles
4	Bretelles pour pantalons	Du type se croisant dans le dos
5	Chemise	Flanelle de laine et nylon
6	Pantalon	Satin de coton et nylon résistant au vent
7	Doublure de pantalon	Nylon matelassé, 6,2 oz
8	Bottes isolées pour temps froid	Caoutchouc, avec détendeur
9	Manteau	Satin de coton et nylon résistant au vent, 8,5 oz
10	Doublure de manteau	Nylon matelassé, 6,2 oz
11	Parka	Tissu Oxford coton et nylon, sans capuchon
12	Doublure de parka	Nylon matelassé, 6,2 oz
13	Bonnet sous-casque isolant	Tissu Oxford coton et nylon
14	Capuchon d'hiver	Tissu Oxford coton et nylon
15	Gants	En cuir noir avec sous-gants en tricot de laine et nylon

VÊTEMENTS FACULATIFS en GRIS

Le nettoyage et l'application de la glace sur l'aile que vous inspecterez prendra un certain temps. Nous vous suggérons d'apporter quelque chose pour occuper pendant les périodes d'attente entre les sessions.

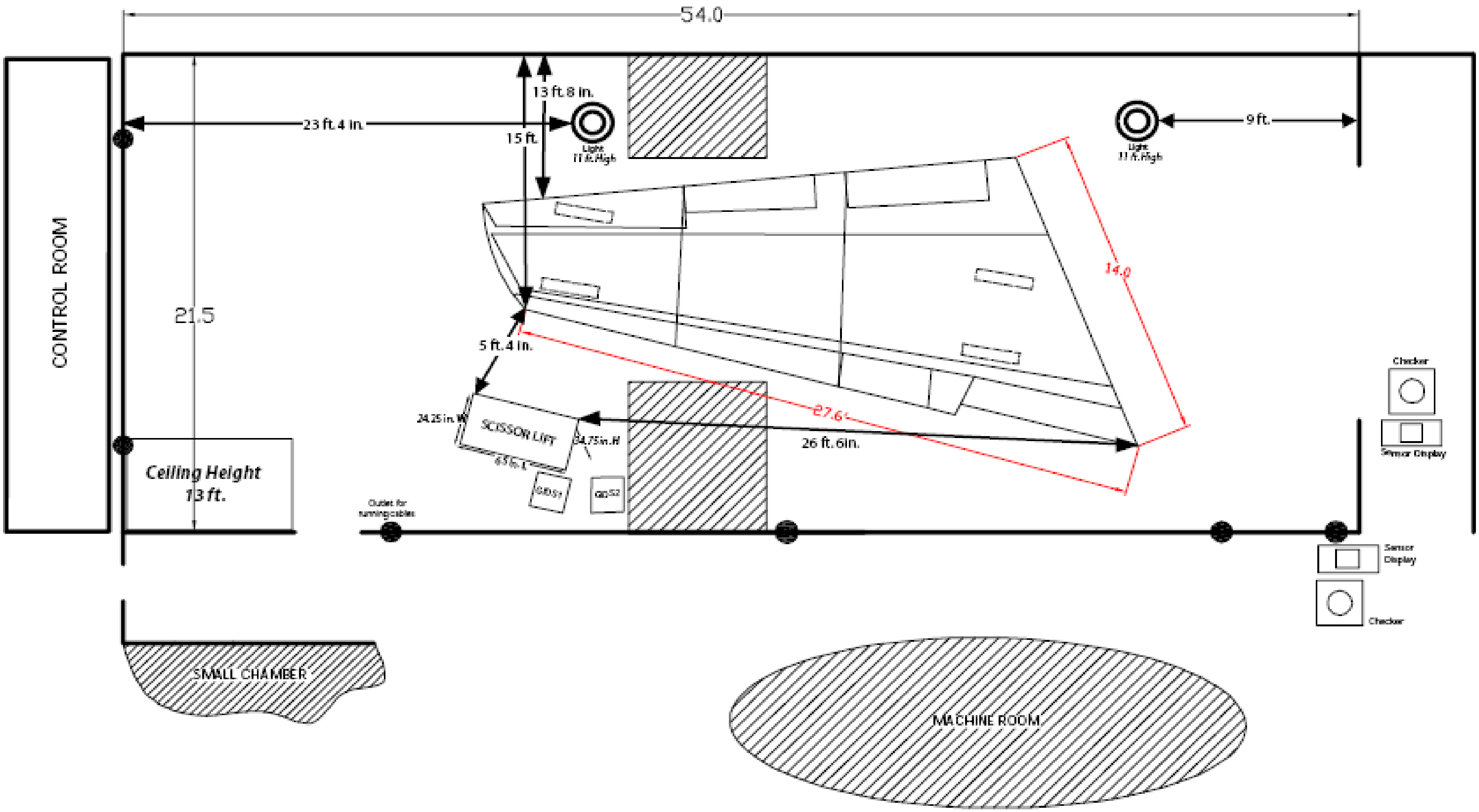
Si vous avez des questions, n'hésitez pas à me téléphoner, au numéro ci-dessous. Au plaisir de vous rencontrer!

Edmundo Sierra
Ergonome
(609) 485-7360

CONSERVEZ CETTE LETTRE POUR VOS DOSSIERS

APPENDIX D

DIAGRAM OF CHAMBER SETUP


54.0
CONTROL ROOM
21.5
23 ft. 4 in.
13 ft. 8 in.
15 ft.
Light
11 ft. High
9 ft.
Light
11 ft. High
14.0
5 ft. 4 in.
27.6'
26 ft. 6in.
24.25 in. W
SCISSOR LIFT
34.75 in. H
65 in. L
Ceiling Height
13 ft.
Outlet for
running cables
Checker
Sensor Display
Sensor
Display
Checker
SMALL CHAMBER
MACHINE ROOM

APPENDIX E

MATERIAL SAFETY DATA SHEET

Dow (hereinafter, and for purposes of this MSDS only, refers to The Dow Chemical Company and to Dow Chemical Canada Inc.) encourages and expects you to read and understand the entire MSDS, as there is important information throughout the document. Dow expects you to follow the precautions identified in this document unless your use conditions would necessitate other appropriate methods or actions.

Chemical Product and Company Identification

Identification

Product Name UCAR(TM) AIRCRAFT DEICING FLUID CONCENTRATE SAE/ISO TYPE I

Company Identification

The Dow Chemical Company
Midland, MI 48674

Emergency Telephone Number

24-HOUR EMERGENCY TELEPHONE NUMBER: (989)636-4400.
Customer Information Number: 1-800-258-2436.

Composition Information

Component	CAS #	Amount (%W/W)
Ethylene glycol	107-21-1	92 %
Water	7732-18-5	7.5 %
Non-hazardous processing additives	Not available	0.5 %

Hazards Identification

Emergency Overview

Appearance Orange

Physical State Liquid

Odor Sweet

Hazards of product

HARMFUL OR FATAL IF SWALLOWED.
MAY CAUSE EYE IRRITATION.
MAY CAUSE RESPIRATORY TRACT IRRITATION.

ISOLATE AREA.
KEEP UPWIND OF SPILL.
STAY OUT OF LOW AREAS.

Potential Health Effects

Effects of Single Acute Overexposure

Inhalation At room temperature, exposure to vapor is minimal due to low volatility. With good ventilation, single exposure is not expected to cause adverse effects. If material is heated or areas are poorly ventilated, vapor/mist may accumulate and cause respiratory irritation and symptoms such as headache and nausea.

Eye Contact May cause slight eye irritation. Corneal injury is unlikely. Vapor or mist may cause eye irritation.

Skin Contact Brief contact is essentially nonirritating to skin. Prolonged contact may cause slight skin irritation with local redness. Repeated contact may cause skin irritation with local redness.

Skin Absorption Prolonged skin contact is unlikely to result in absorption of harmful amounts. Repeated skin exposure to large quantities may result in the absorption of harmful amounts. Massive contact with damaged skin or of material sufficiently hot to burn skin may result in absorption of potentially lethal amounts.

Swallowing Oral toxicity is expected to be moderate in humans due to ethylene glycol even though tests with animals show a lower degree of toxicity. The lethal dose in adult humans for ethylene glycol is approximately 3 ounces (100 ml) (1/3 cup). Swallowing may result in severe effects, even death. May cause nausea or vomiting. May cause abdominal discomfort or diarrhea. Excessive exposure may cause central nervous system effects, cardiopulmonary effects (metabolic acidosis), and kidney failure.

Chronic, Prolonged or Repeated Overexposure

Effects of Repeated Overexposure Repeated excessive exposure may cause irritation of the upper respiratory tract. For ethylene glycol: In humans, effects have been reported on the following organs: Central nervous system. Observations in humans include: Nystagmus (involuntary eye movement). In animals, effects have been reported on the following organs: Kidney, liver. Based on animal studies, ingestion of very large amounts of ethylene glycol appears to be the major and possibly only route of exposure to produce birth defects. Exposures by inhalation or skin contact, the primary routes of occupational exposure, had minimal effect on the fetus, in animal studies. Ingestion of large amounts of ethylene glycol has been shown to interfere with reproduction in animals.

Other Effects of Overexposure **No information available.**

See Section 11 for toxicological information and additional information about potential health effects.

Potential Environmental Effects

See Section 12 for Ecological Information.

First Aid Procedures

Inhalation

Move person to fresh air; if effects occur, consult a physician.

Eye Contact

Flush eyes thoroughly with water for several minutes. Remove contact lenses after the initial 1-2 minutes and continue flushing for several additional minutes. If effects occur, consult a physician, preferably an ophthalmologist.

Skin Contact

Immediately flush skin with water while removing contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Destroy contaminated leather items such as shoes, belts, and watchbands.

Swallowing

Do not induce vomiting. Seek medical attention immediately. If person is fully conscious give 1 cup or 8 ounces (240 ml) of water. If medical advice is delayed and if an adult has swallowed several ounces of chemical, then give 3-4 ounces (1/3-1/2 cup) (90-120 ml) of hard liquor such as 80 proof whiskey. For children, give proportionally less liquor at a dose of 0.3 ounce (1 1/2 tsp.) (8 ml) liquor for each 10 pounds of body weight, or 2 ml per kg body weight [e.g., 1.2 ounce (2 1/3 tbsp.) for a 40 pound child or 36 ml for an 18 kg child].

Notes to Physician

If several ounces of EG have been ingested, early administration of ethanol may counter the toxic effects (metabolic acidosis, renal damage). Consider hemodialysis or peritoneal dialysis & thiamine 100 mg plus pyridoxine 50 mg IV every 6 hr.

If ethanol is used, a therapeutically effective blood concentration in the range of 100 - 150 mg/dl may be achieved by a rapid loading dose followed by a continuous intravenous infusion. Consult standard literature for details of treatment.

4-Methyl pyrazole (Antizol®) is an effective blocker of alcohol dehydrogenase and should be used in the treatment of ethylene glycol, di- or triethylene glycol, ethylene glycol butyl ether, or methanol intoxication if available.

Fomepizole protocol (Brent, J. et al., New England Journal of Medicine, Feb. 8, 2001, 344:6, p. 424-9): loading dose 15 mg/kg IV, follow by bolus dose of 10 mg/kg every 12 hours; after 48 hours, increase bolus dose to 15 mg/kg every 12 hours.

Continue fomepizole until serum methanol, EG, DEG, or TEG are undetectable. The signs and symptoms of poisoning include anion gap metabolic acidosis, CNS depression, renal tubular injury, and possible late stage cranial nerve involvement.
Respiratory symptoms, including pulmonary edema, may be delayed. Persons receiving significant exposure should be observed 24-48 hours for signs of respiratory distress.
In severe poisoning, respiratory support with mechanical ventilation and positive end expiratory pressure may be required.
If lavage is performed, suggest endotracheal and/or esophageal control. Danger from lung aspiration must be weighed against toxicity when considering emptying the stomach.

Fire Fighting Measures

Flammable Properties - Refer to Section 9, PHYSICAL AND CHEMICAL PROPERTIES
Extinguishing Media
Water fog or fine spray. Dry chemical fire extinguishers. Carbon dioxide fire extinguishers. Foam. Do not use direct water stream. May spread fire. Alcohol resistant foams (ATC type) are preferred. General purpose synthetic foams (including AFFF) or protein foams may function, but will be less effective.
Fire Fighting Procedures
Keep people away. Isolate fire and deny unnecessary entry. Use water spray to cool fire exposed containers and fire affected zone until fire is out and danger of reignition has passed. Fight fire from protected location or safe distance. Consider the use of unmanned hose holders or monitor nozzles. Immediately withdraw all personnel from the area in case of rising sound from venting safety device or discoloration of the container. Burning liquids may be extinguished by dilution with water. Do not use direct water stream. May spread fire. Move container from fire area if this is possible without hazard. Burning liquids may be moved by flushing with water to protect personnel and minimize property damage.
Special Protective Equipment for Firefighters
Wear positive-pressure self-contained breathing apparatus (SCBA) and protective fire fighting clothing (includes fire fighting helmet, coat, pants, boots, and gloves). If protective equipment is not available or not used, fight fire from a protected location or safe distance.
Unusual Fire and Explosion Hazards
Container may rupture from gas generation in a fire situation.
Violent steam generation or eruption may occur upon application of direct water stream to hot liquids.

Hazardous Combustion Products
During a fire, smoke may contain the original material in addition to combustion products of varying composition which may be toxic and/or irritating. Combustion products may include and are not limited to: Carbon monoxide. Carbon dioxide.

Accidental Release Measures

Steps to be Taken if Material is Released or Spilled:

Contain spilled material if possible. Small spills: Absorb with materials such as: Cat litter. Sand. Sawdust. Vermiculite. Zorb-all®. Hazorb®. Large spills: Dike area to contain spill. Pump into suitable and properly labeled containers. See Section 13, Disposal Considerations, for additional information.

Personal Precautions: Use appropriate safety equipment. For additional information, refer to Section 8, Exposure Controls and Personal Protection.   Isolate area.   Refer to Section 7, Handling for additional precautionary measures.   Keep unnecessary and unprotected personnel from entering the area.   Keep personnel out of low areas.   Keep upwind of spill.   Ventilate area of leak or spill.

Environmental Precautions: Prevent from entering into soil, ditches, sewers, waterways and/ or groundwater. See Section 12, Ecological Information.

Handling and Storage

Handling

General Handling

Do not swallow.
Avoid contact with eyes.
Avoid breathing mist.
Wash thoroughly after handling.
Keep container closed.
Use with adequate ventilation.

See Section 8, EXPOSURE CONTROLS AND PERSONAL PROTECTION.

Ventilation

Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Other Precautions

Spills of these organic materials on hot fibrous insulations may lead to lowering of the autoignition temperatures possibly resulting in spontaneous combustion.
Storage

Additional storage and handling information on this product may be obtained by calling your Dow sales or customer service contact. Ask for a product brochure.
Exposure Controls and Personal Protection

Exposure Limits

Component	Exposure Limits	Skin.	Form
Ethylene glycol	100 mg/m3 CEILING ACGIH		Aerosol, vapor, and mist

In the Exposure Limits Chart above, if there is no specific qualifier (i.e., Aerosol) listed in the Form Column for a particular limit, the listed limit includes all airborne forms of the substance that can be inhaled.

A "Yes" in the Skin Column indicates a potential significant contribution to overall exposure by the cutaneous (skin) route, including mucous membranes and the eyes, either by contact with vapors or by direct skin contact with the substance. A "Blank" in the Skin Column indicates that exposure by the cutaneous (skin) route is not a potential significant contributor to overall exposure.

Personal Protection

Respiratory Protection: Atmospheric levels should be maintained below the exposure guideline. When airborne exposure guidelines and/or comfort levels may be exceeded, use an approved air-purifying respirator.

Ventilation: Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Eye Protection: Use safety glasses.
If exposure causes eye discomfort, use a full-face respirator.

Other Protective Equipment: When prolonged or frequently repeated contact could occur, use chemically protective clothing resistant to this material. Selection of specific items such as faceshield, gloves, boots, apron, or full-body suit will depend on operation.
If hands are cut or scratched, use gloves chemically resistant to this material even for brief exposures.
When handling hot material, protect skin from thermal burns as well as from skin absorption.

Physical and Chemical Properties

Physical State: Liquid

Appearance: Orange

Odor: Sweet

Flash Point - Closed Cup: *Pensky-Martens Closed Cup ASTM D 93* None.

Flash Point - Open Cup: **135 °C 275 °F** *Cleveland Open Cup ASTM D 92*

Flammable Limits In Air:

Lower *Not Determined, Aqueous System*
Upper *Not Determined, Aqueous System*

Autoignition Temperature: ***Not applicable.***

Vapor Pressure: 2.7 mmHg *20 °C*

Boiling Point (760 mmHg): 152 °C 306 °F

Vapor Density (air = 1): 1.8

Specific Gravity (H2O = 1): 1.1 *20 °C / 20 °C*

Liquid Density: 9.3 lb/gal *15.56 °C*

Freezing Point: -28 °C -18 °F

Melting Point: *No test data available.*

Solubility in Water (by weight): 100 % *20 °C*

pH: 7 - 9

Octanol/Water Partition Coefficient - Measured: -1.36

Evaporation Rate (Butyl Acetate = 1): 0.2

Percent Volatiles: 100 Wt%

Stability and Reactivity

Stability/Instability Thermally stable at recommended temperatures and pressures.

Conditions to Avoid: Exposure to elevated temperatures can cause product to decompose. Generation of gas during decomposition can cause pressure in closed systems.

Incompatible Materials: Avoid contact with: Strong acids. Strong bases. Strong oxidizers.

Thermal Decomposition: Decomposition products depend upon temperature, air supply and the presence of other materials. Decomposition products can include and are not limited to: Aldehydes. Alcohols. Ethers.

Hazardous Polymerization Will not occur.

Toxicological Information

The following information is applicable to the major component, ethylene glycol.

Acute Toxicity

Peroral

Rat; LD50 = > 5000 mg/kg

Peroral

Human; Lethal Dose; approximately 3 ounces (100 ml) (1/3 cup)

Percutaneous

Rabbit; LD50 = > 20000 mg/kg

Inhalation

Aerosol exposure Rat; 7 hours; LC50 = > 3.95 mg/L

DEVELOPMENTAL TOXICITY

Based on animal studies, ingestion of very large amounts of ethylene glycol appears to be the major and possibly only route of exposure to produce birth defects., Exposures by inhalation or skin contact, the primary routes of occupational exposure, had minimal effect on the fetus, in animal studies.

REPRODUCTIVE TOXICITY

Ingestion of large amounts of ethylene glycol has been shown to interfere with reproduction in animals.

CHRONIC TOXICITY AND CARCINOGENICITY

Ethylene glycol did not cause cancer in long-term animal studies.

GENETIC TOXICOLOGY

In Vitro

For ethylene glycol:, In vitro genetic toxicity studies were negative.

In Vivo

For ethylene glycol:, Animal genetic toxicity studies were negative.

SIGNIFICANT DATA WITH POSSIBLE RELEVANCE TO HUMANS

Repeated excessive exposure may cause irritation of the upper respiratory tract.
For ethylene glycol:
In humans, effects have been reported on the following organs:
Central nervous system.

Observations in humans include:
Nystagmus (involuntary eye movement).
In animals, effects have been reported on the following organs:
Kidney, liver.

Ecological Information

Environmental Fate

Based largely or completely on data for major component(s): Ethylene glycol. Material is readily biodegradable. Passes OECD test(s) for ready biodegradability.
BOD (% Oxygen consumption)
Based largely or completely on information for this product:

	Day 5	**Day 10**	**Day 15**	**Day 20**	**Day 28/30**
	69 %	85 %		96 %	

Ecotoxicity

Based largely or completely on information for this product:, Material is practically non-toxic to aquatic organisms on an acute basis (LC50/EC50 >100 mg/L in the most sensitive species tested).

Toxicity to Micro-organisms
Based largely or completely on information for this product:
bacteria; 16 h; Growth inhibition; EC50
Result value: > 10000 mg/L

Toxicity to Aquatic Invertebrates
Based largely or completely on information for this product:
water flea Daphnia magna; Acute LC50
Result value: 43420 mg/L

Toxicity to Aquatic Invertebrates
Based largely or completely on information for this product:
water flea Daphnia magna; Acute immobilization EC50
Result value: 42900 mg/L

Toxicity to Fish
Based largely or completely on information for this product:
rainbow trout (Oncorhynchus mykiss); Acute LC50
Result value: 11600 mg/L

Toxicity to Fish
Based largely or completely on information for this product:
fathead minnow (Pimephales promelas); Acute LC50
Result value: 18400 mg/L

Further Information
Based largely or completely on information for: Ethylene glycol. Bioconcentration potential is low (BCF < 100 or Log Pow < 3). Potential for mobility in soil is very high (Koc between 0 and 50). Soil organic carbon/water partition coefficient (Koc) is estimated to be: 1.
Theoretical Oxygen Demand (THOD) - calculated:: 1.30 mg/mg

Octanol/Water Partition Coefficient - Measured: -1.36

Disposal Considerations

Disposal
All disposal practices must be in compliance with all Federal, State/Provincial and local laws and regulations. Regulations may vary in different locations. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator. DOW HAS NO CONTROL OVER THE MANAGEMENT PRACTICES OR MANUFACTURING PROCESSES OF PARTIES HANDLING OR USING THIS MATERIAL. THE INFORMATION PRESENTED HERE PERTAINS ONLY TO THE PRODUCT AS SHIPPED IN ITS INTENDED CONDITION AS DESCRIBED IN MSDS SECTION 2 (Composition/ Information on Ingredients). FOR UNUSED & UNCONTAMINATED PRODUCT, the preferred options include sending to a licensed, permitted: Reclaimer. Recycler. Incinerator or other thermal destruction device. Waste water treatment system. As a service to its customers, Dow can provide names of information resources to help identify waste management companies and other facilities which recycle, reprocess or manage chemicals or plastics, and that manage used drums. Telephone Dow's Customer Information Group at 1-800-258-2436 or 1-989-832-1556 (U.S.), or 1-800-331-6451 (Canada) for further details .

Transport Information

U.S. D.O.T.

NON-BULK
Proper Shipping Name : NOT REGULATED

BULK
Proper Shipping Name : OTHER REGULATED SUBSTANCES, LIQUID, NOS
Technical Name : CONTAINS ETHYLENE GLYCOL
Hazard Class : 9
ID Number : NA3082
Packing Group : PG III

Reportable Quantity : 5,438 LB

This information is not intended to convey all specific regulatory or operational requirements/information relating to this product. Additional transportation system information can be obtained through an authorized sales or customer service representative. It is the responsibility of the transporting organization to follow all applicable laws, regulations and rules relating to the transportation of the material.

Regulatory Information

Federal/National

OSHA HAZARD COMMUNICATION STANDARD

This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 TITLE III (EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986) SECTION 313

This product contains the following substances which are subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act 1986 and which are listed in 40 CFR Part 372.

Component	CAS #	Amount
Ethylene glycol	107-21-1	<= 92.0000%

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (CERCLA) SECTION 103

This product contains the following substances which are subject to CERCLA Section 103 reporting requirements and which are listed in 40 CFR 302.4.

Component	CAS #	Amount
Ethylene glycol	107-21-1	<= 92.0000%

Superfund Amendments and Reauthorization Act of 1986 Title III (Emergency Planning and Community Right-to-Know Act of 1986) Section 302

To the best of our knowledge this product does not contain chemicals at levels which require reporting under this statute.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 TITLE III (EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT OF 1986) SECTIONS 311 AND 312

Delayed (Chronic) Health Hazard : Yes
Fire Hazard : No
Immediate (Acute) Health Hazard : Yes
Reactive Hazard : No
Sudden Release of Pressure Hazard : No

TOXIC SUBSTANCES CONTROL ACT (TSCA)

All components of this product are on the TSCA Inventory or are exempt from TSCA Inventory requirements under 40 CFR 720.30.

EUROPEAN INVENTORY OF EXISTING COMMERCIAL CHEMICAL SUBSTANCES (EINECS)

The components of this product are on the EINECS inventory or are exempt from EINECS inventory requirements.

CEPA - Domestic Substances List (DSL)

This product contains one or more substances which are not listed on the Canadian Domestic Substances List (DSL). Contact your Dow representative for more information.

State/Local

Pennsylvania (Worker and Community Right-To-Know Act): Pennsylvania Hazardous Substances List and/or Pennsylvania Environmental Hazardous Substance List:

The following product components are cited in the Pennsylvania Hazardous Substance List and/or the Pennsylvania Environmental Substance List, and are present at levels which require reporting.

Component	**CAS #**	**Amount**
Ethylene glycol	107-21-1	<= 92.0000%

PENNSYLVANIA (WORKER AND COMMUNITY RIGHT-TO-KNOW ACT): PENNSYLVANIA SPECIAL HAZARDOUS SUBSTANCES LIST:

To the best of our knowledge this product does not contain chemicals at levels which require reporting under this statute.

CALIFORNIA PROPOSITION 65 (SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT OF 1986)

This product contains no listed substances known to the State of California to cause cancer, birth defects or other reproductive harm, at levels which would require a warning under the statute.

CALIFORNIA SCAQMD RULE 443.1 (SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT RULE 443.1, LABELING OF MATERIALS CONTAINING ORGANIC SOLVENTS)

VOC: Vapor pressure 2.7 mmHg @ 20 °C
1021 g/l
1115 g/l less water and less exempted solvents

This section provides selected regulatory information on this product including its components. This is not intended to include all regulations. It is the responsibility of the user to know and comply with all applicable rules, regulations and laws relating to the product being used.

Other Information

Additional Information

Additional information on this and other Dow products may be obtained by visiting our web page at www.dow.com.
Additional information on this product may be obtained by calling Dow's Customer Information Group at 1-800-258-2436 (U.S.) or 1-800-331-6451 (Canada). Ask for a product brochure.

Hazard Rating System

NFPA ratings for this product are: H - 2 **F -** 1 **R -** 0

These ratings are part of a specific hazard communication program and should be disregarded where individuals are not trained in the use of this hazard rating system. You should be familiar with the hazard communication programs applicable to your workplace.

Recommended Uses and Restrictions

For industrial use.

Dow recommends that you use this product in a manner consistent with the listed use. If your intended use is not consistent with Dow's stated use, please contact Dow's Customer Information Group at 1-800-258-2436 (U.S.) or 1-800-331-6451 (Canada) for more information.

Revision

Version: 9.
Revision: 02/17/2004
Most recent revision(s) are noted by the bold, double bars in left-hand margin throughout this document.

Legend

Bacterial/NA	Non Acclimated Bacteria
F	Fire
H	Health
IHG	Industrial Hygiene Guideline
N/A	Not available
NFPA	National Fire Protection Association
O	Oxidizer
R	Reactivity
TS	Trade secret
VOL/VOL	Volume/Volume
W	Water Reactive
W/W	Weight/Weight

NOTICE: Dow urges each customer or recipient of this MSDS to study it carefully and consult appropriate expertise, as necessary or appropriate, to become aware of and understand the data contained in this MSDS and any hazards associated with the product. The information herein is provided in good faith and believed to be accurate as of the effective date shown above. However, no warranty, express or implied, is given., Regulatory requirements are subject to change and may differ between various locations. It is the buyer's/user's responsibility to ensure that its activities comply with all federal, state, provincial or local laws. The information presented here pertains only to the product as shipped. Since conditions for use of the product are not under the control of Dow, it is the buyer's/user's duty to determine the conditions necessary for the safe use of this product., Due to the proliferation of sources for information such as manufacturer-specific MSDSs, Dow is not and cannot be responsible for MSDSs obtained from any source other than Dow. If you have obtained a Dow MSDS from a non-Dow source or if you are not sure that a Dow MSDS is current, please contact Dow for the most current version

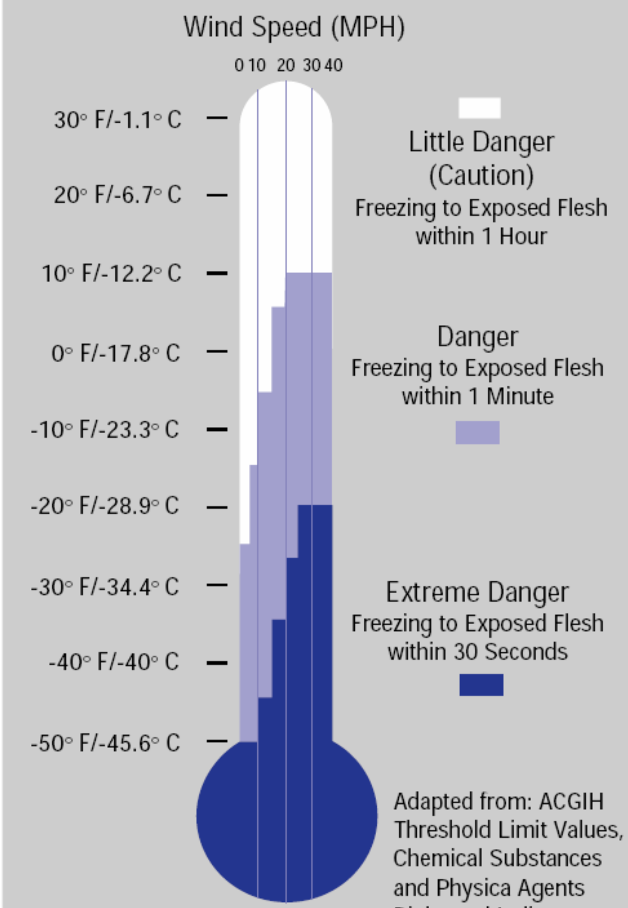
APPENDIX F

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION COLD STRESS CARD

THE COLD STRESS EQUATION

LOW TEMPERATURE + WIND SPEED + WETNESS = INJURIES & ILLNESS

When the body is unable to warm itself, serious cold-related illnesses and injuries may occur, and permanent tissue damage and death may result. **Hypothermia** can occur when *land temperatures* are **above** freezing or *water temperatures* are below 98.6°F/ 37°C. Cold-related illnesses can slowly overcome a person who has been chilled by low temperatures, brisk winds, or wet clothing.



Adapted from: ACGIH Threshold Limit Values, Chemical Substances and Physica Agents Biohazard Indices, 1998-1999.

U.S. Department of Labor
Occupational Safety and Health Administration

OSHA 3156
1998

FROST BITE

What Happens to the Body:

FREEZING IN DEEP LAYERS OF SKIN AND TISSUE; PALE, WAXY-WHITE SKIN COLOR; SKIN BECOMES HARD and NUMB; USUALLY AFFECTS THE FINGERS, HANDS, TOES, FEET, EARS, and NOSE.

What Should Be Done: (land temperatures)

- Move the person to a warm dry area. Don't leave the person alone.
- Remove any wet or tight clothing that may cut off blood flow to the affected area.
- **DO NOT** rub the affected area, because rubbing causes damage to the skin and tissue.
- **Gently** place the affected area in a warm (105°F) water bath and monitor the water temperature to **slowly** warm the tissue. Don't pour warm water directly on the affected area because it will warm the tissue too fast causing tissue damage. Warming takes about 25-40 minutes.
- After the affected area has been warmed, it may become puffy and blister. The affected area may have a burning feeling or numbness. When normal feeling, movement, and skin color have returned, the affected area should be dried and wrapped to keep it warm. **NOTE:** If there is a chance the affected area may get cold again, do not warm the skin. If the skin is warmed and then becomes cold again, it will cause severe tissue damage.
- Seek medical attention as soon as possible.

HYPOTHERMIA - (Medical Emergency)

What Happens to the Body:

NORMAL BODY TEMPERATURE (98.6° F/37°C) DROPS TO OR BELOW 95°F (35° C); FATIGUE OR DROWSINESS; UNCONTROLLED SHIVERING; COOL BLUISH SKIN; SLURRED SPEECH; CLUMSY MOVEMENTS; IRRITABLE, IRRATIONAL OR CONFUSED BEHAVIOR.

What Should Be Done: (land temperatures)

- Call for emergency help (i.e., Ambulance or Call 911).
- Move the person to a warm, dry area. Don't leave the person alone. Remove any wet clothing and replace with warm, dry clothing or wrap the person in blankets.
- Have the person drink warm, sweet drinks (sugar water or sports-type drinks) if they are alert. **Avoid drinks with caffeine** (coffee, tea, or hot chocolate) or alcohol.
- Have the person move their arms and legs to create muscle heat. If they are unable to do this, place warm bottles or hot packs in the arm pits, groin, neck, and head areas. **DO NOT** rub the person's body or place them in warm water bath. This may stop their heart.

What Should Be Done: (water temperatures)

- Call for emergency help (Ambulance or Call 911). Body heat is lost up to 25 times faster in water.
- **DO NOT** remove any clothing. Button, buckle, zip, and tighten any collars, cuffs, shoes, and hoods because the layer of trapped water closest to the body provides a layer of insulation that slows the loss of heat. Keep the head out of the water and put on a hat or hood.
- Get out of the water as quickly as possible or climb on anything floating. **DO NOT** attempt to swim unless a floating object or another person can be reached because swimming or other physical activity uses the body's heat and reduces survival time by about 50 percent.
- If getting out of the water is not possible, wait quietly and conserve body heat by folding arms across the chest, keeping thighs together, bending knees, and crossing ankles. If another person is in the water, huddle together with chests held closely.

How to Protect Workers

- Recognize the environmental and workplace conditions that lead to potential cold-induced illnesses and injuries.
- Learn the signs and symptoms of cold-induced illnesses/injuries and what to do to help the worker.
- Train the workforce about cold-induced illnesses and injuries.
- Select proper clothing for cold, wet, and windy conditions. Layer clothing to adjust to changing environmental temperatures. Wear a hat and gloves, in addition to underwear that will keep water away from the skin (polypropylene).
- Take frequent short breaks in warm dry shelters to allow the body to warm up.
- Perform work during the warmest part of the day.
- Avoid exhaustion or fatigue because energy is needed to keep muscles warm.
- Use the buddy system (work in pairs).
- Drink warm, sweet beverages (sugar water, sports-type drinks). Avoid drinks with caffeine (coffee, tea, or hot chocolate) or alcohol.
- Eat warm, high-calorie foods like hot pasta dishes.

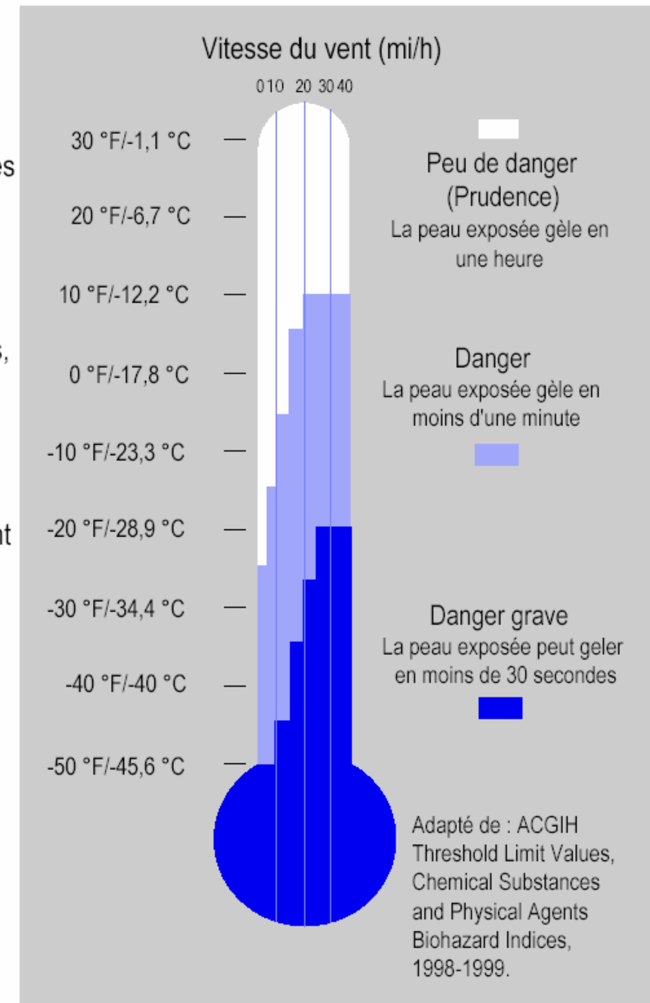
Workers Are at Increased Risk When…

- They have predisposing health conditions such as cardiovascular disease, diabetes, and hypertension.
- They take certain medication (check with your doctor, nurse, or pharmacy and ask if any medicines you are taking affect you while working in cold environments).
- They are in poor physical condition, have a poor diet, or are older.

ÉQUATION DU STRESS DÛ AU FROID

BASSE TEMPÉRATURE + VITESSE DU VENT + HUMIDITÉ = BLESSURES ET MALADIES

Lorsque l'organisme ne réussit pas à se réchauffer lui-même, des blessures et maladies graves reliées au froid peuvent survenir, lesquelles peuvent entraîner des dommages permanents aux tissus, voire la mort. L'**hypothermie** peut survenir quand la *température de l'air* est **au-dessus** du point de congélation ou quand la *température de l'eau* est inférieure à 98,6 °F/37 °C. Les maladies dues au froid peuvent finir par avoir raison d'une personne exposée à des basses températures, à des vents intenses ou à l'humidité de vêtements mouillés.



U.S. Department of Labor
Occupational Safety and Health Administration

OSHA 3156
1998

GELURE

Ce qui arrive à l'organisme :

CONGÉLATION DES COUCHES PROFONDES DE LA PEAU ET DES TISSUS; PEAU BLANCHE ET D'APPARENCE CIREUSE; LA PEAU DEVIENT DURE AU TOUCHER et ENGOURDIE; AFFECTE HABITUELLEMENT LES DOIGTS, LES MAINS, LES ORTEILS, LES PIEDS, LES OREILLES et LE NEZ

Ce qu'il faut faire : (basse température de l'air)

- Évacuer la personne vers un local chaud et sec. Ne pas laisser la personne seule.
- Retirer les vêtements mouillés et tout vêtement serré qui pourrait gêner la circulation du sang dans la zone touchée.
- **NE PAS** frictionner la zone touchée, car cela pourrait causer des dommages à la peau et aux tissus.
- Placer **doucement** la zone touchée dans un bain d'eau chaude (105 °F/40,5 °C) et contrôler la température de l'eau, afin de réchauffer **lentement** les tissus. Ne pas verser d'eau chaude directement sur la zone touchée, car cela pourrait endommager les tissus en les réchauffant trop rapidement. Le réchauffement doit prendre environ 25 à 40 minutes.
- Une fois la zone touchée réchauffée, il est possible qu'une enflure et des cloques apparaissent et qu'une sensation de brûlure ou un engourdissement se manifestent. Lorsque les sensations, les mouvements et la couleur de la peau reviennent à la normale, sécher la zone touchée et la couvrir pour la garder au chaud. **NOTA** : Si la zone touchée doit de nouveau être exposée au froid, ne pas réchauffer la peau. Si la peau est réchauffée et qu'elle refroidit de nouveau, les tissus risquent d'être lourdement endommagés.
- Obtenir des soins médicaux sans tarder.

HYPORTHERMIE - (Urgence médicale)

Ce qui arrive à l'organisme :

LA TEMPÉRATURE NORMALE DU CORPS (98,6 °F/37 °C) DESCEND À 95 °C (35 °C) OU PLU BAS; FATIGUE OU SOMNOLENCE; FRISSONNEMENTS INCONTRÔLÉS; PEAU FROIDE ET BLEUÂTRE; ÉLOCUTION DIFFICILE; MOUVEMENTS MALADROITS; COMPORTEMENT IRRIT IRRATIONNEL OU CONFUS.

Ce qu'il faut faire : (baisse température de l'air)

- Appeler les secours (ambulanciers ou 911).
- Évacuer la personne vers un local chaud et sec. Ne pas laisser la personne seule. Retirer les vêteme mouillés et les remplacer par des vêtements chauds et secs ou emmitoufler la personne dans des cou
- Donner à la personne des boissons tièdes et sucrées (eau sucrée ou boissons énergétiques), si elle est bien éveillée. **Évitez les boissons contenant de la caféine** (café, thé, chocolat chaud) ou de l'
- Demander à la personne de bouger les bras et les jambes (la contraction des muscles produit de la Si elle est incapable de bouger, lui placer des bouillottes ou des compresses chaudes sous les aisse à l'aine, dans le cou et sur la tête. **NE PAS** la frictionner ni la bouger dans un bain chaud. Cela pourr causer un arrêt cardiaque.

Ce qu'il faut faire : (basse température de l'eau)

- Appeler les secours (ambulanciers ou 911). La température corporelle s'abaisse 25 fois plus vite dan l'eau que sur terre.
- **NE** retirer **AUCUN** vêtement. Attacher les boutons et les agrafes, et fermer les fermetures à glissière en serrant bien les cols, poignets, souliers et capuchons, car la couche d'eau emprisonnée près du corps joue le rôle d'un isolant et ralentit la perte de chaleur. Garder la tête hors de l'eau, couverte d'un chapeau ou d'un capuchon.
- Sortir de l'eau au plus vite ou se hisser sur un objet flottant. **NE PAS** essayer de nager à moins que ce soit pour atteindre un objet flottant ou pour rejoindre quelqu'un d'autre, car le fait de nager ou une autre activité physique dissipe la chaleur corporelle et réduit le temps de survie d'environ 50 p. 100.
- Si vous ne pouvez pas sortir de l'eau, attendez calmement et ménagez votre chaleur corporelle en p la position suivante : bras repliés sur la poitrine, cuisses serrées, genoux pliés et chevilles croisées. a quelqu'un d'autre à l'eau, blottissez-vous l'un contre l'autre, poitrine contre poitrine.

Comment protéger les travailleurs

- Prendre conscience des conditions ambiantes et des conditions du milieu de travail pouvant mener à des blessures ou des maladies dues au froid.
- Apprendre les signes et les symptômes des maladies/blessures dues au froid et savoir ce qu'il faut faire pour venir en aide au travailleur touché.
- Donner de la formation aux travailleurs sur les maladies et les blessures dues au froid.
- Choisir des vêtements appropriés pour l'exposition au froid, à l'humidité et au vent. Porter plusieurs couches de vêtements afin de pouvoir mieux s'adapter aux changements de température ambiante. Porter un chapeau et des gants, ainsi que des sous-vêtements (en polypropylène) qui empêchent l'humidité d'entrer en contact avec la peau.
- Prendre fréquemment de courtes pauses dans des abris chauds et secs, pour permettre au corps de se réchauffer.
- Exécuter les travaux pendant la période la plus chaude de la journée.
- Éviter de s'épuiser ou de se fatiguer, car il faut de l'énergie pour garder les muscles au chaud.
- Utiliser un système de jumelage (travailler deux par deux).
- Boire des boissons chaudes et sucrées (eau chaude, boissons énergétiques). Éviter les boissons contenant de la caféine (café, thé ou chocolat chaud) ou de l'alcool.
- Manger des aliments chauds contenant beaucoup de calories, comme des plats chauds de pâtes.

Les travailleurs sont exposés à un risque accru si...

- Ils ont un problème de santé prédisposant, comme une maladie cardiovasculaire, le diabète et l'hypertension.
- Ils prennent certains médicaments (vérifiez auprès de votre médecin, une infirmière ou votre pharmacien si les médicaments que vous prenez ont des effets particuliers lorsque vous travaillez dans des environnements froids).
- Ils sont en mauvaise condition physique, s'alimentent mal ou sont âgés.

APPENDIX G

EMERGENCY POSTER

EMERGENCY

1 Alert the Test Staff

2 Call the Safety Department
(450) 430-7981

IF NO ONE IS AVAILABLE
Call 911

FOR FROST BITE OR HYPOTHERMIA
Follow procedures in the blue folder marked FROST BITE/HYPOTHERMIA hanging outside the chamber door.

FOR DEICING FLUID POISON/CONTACT
Follow procedures in orange folder marked DEICING FLUID EMERGENCY hanging outside the chamber door.

URGENCE

1. Alertez les responsables de l'expérience

2. Appelez le Service de sécurité (450) 430-7981

SI PERSONNE NE RÉPOND
Appelez le 911

GELURE OU HYPOTHERMIE :
Suivez les instructions indiquées dans la chemise bleue marquée GELURE/HYPOTHERMIE, située à l'entrée de la chambre froide.

INTOXICATION PAR/CONTACT AVEC DU LIQUIDE DE DÉGIVRAGE :
Suivez les instructions indiquées dans la chemise orange marquée URGENCE – LIQUIDE DE DÉGIVRAGE située à l'entrée de la chambre froide.

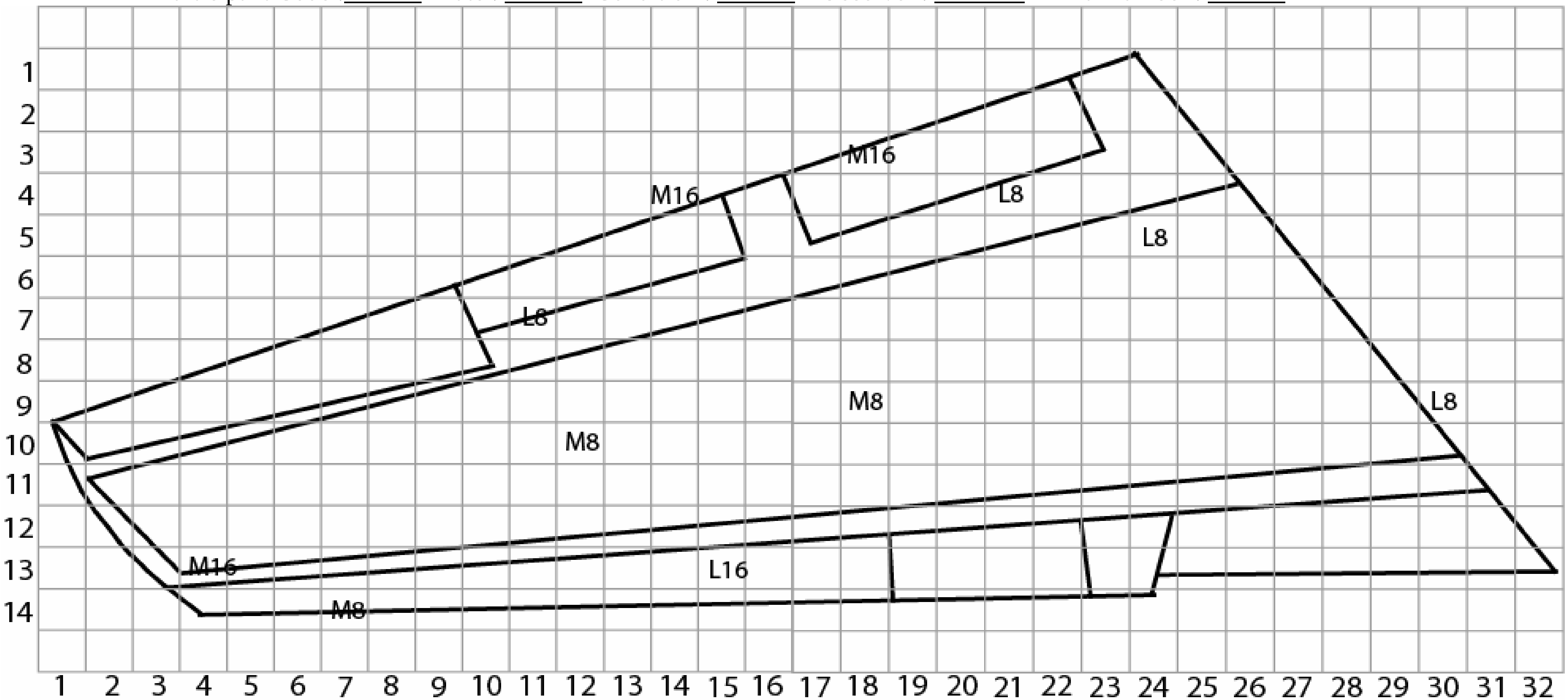
APPENDIX H

HIGH CONTAMINATION TEST ADMINISTRATION FORM

LOW CONTAMINATION TEST ADMINISTRATION FORM

Test Diagram – Day 1 High Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Visual inspection time: _______
Total inspection time: ______

Based on your **visual** inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________

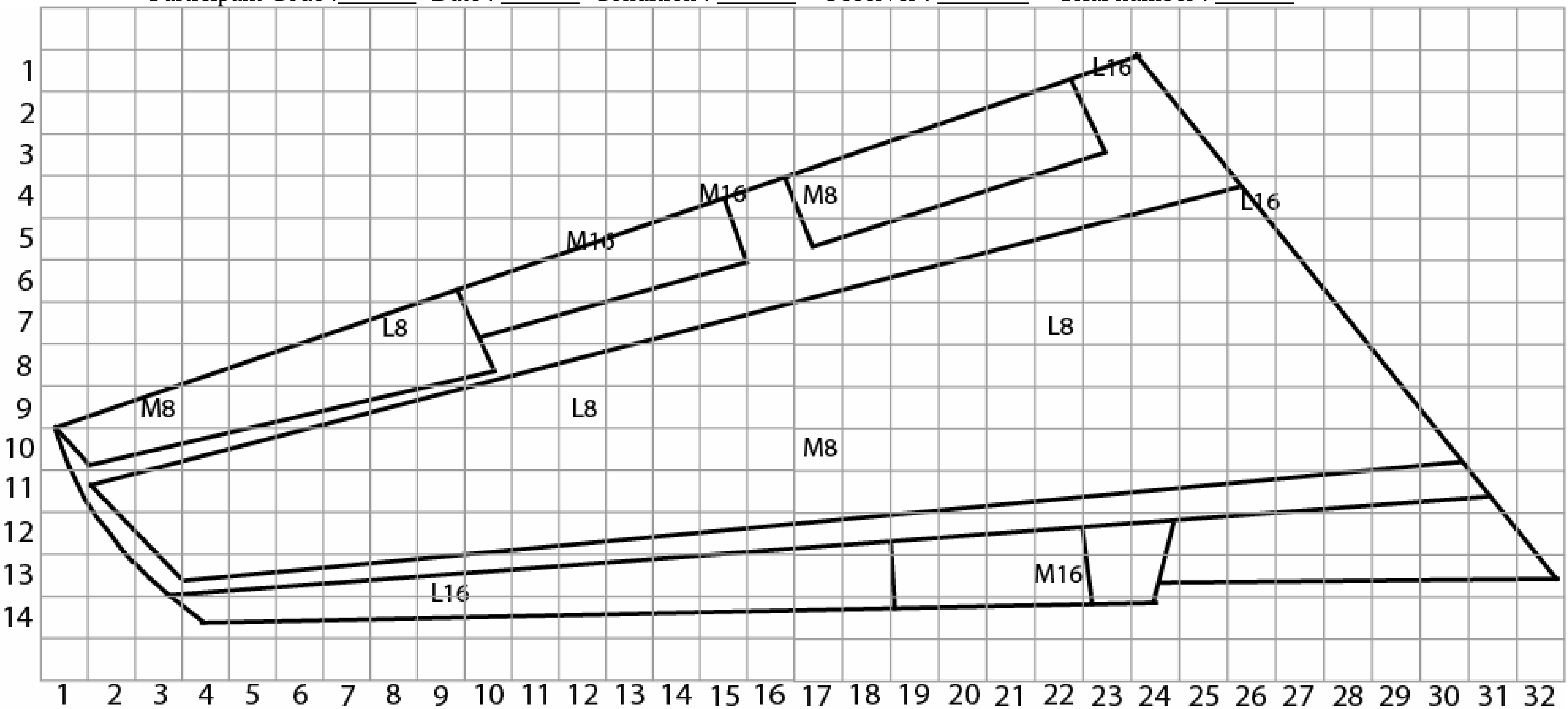
Comments/Interesting events:

____

____

Visual Test Diagram – Day 2 High Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Visual inspection time: _______
Total inspection time: ______

Based on your **visua**l inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________

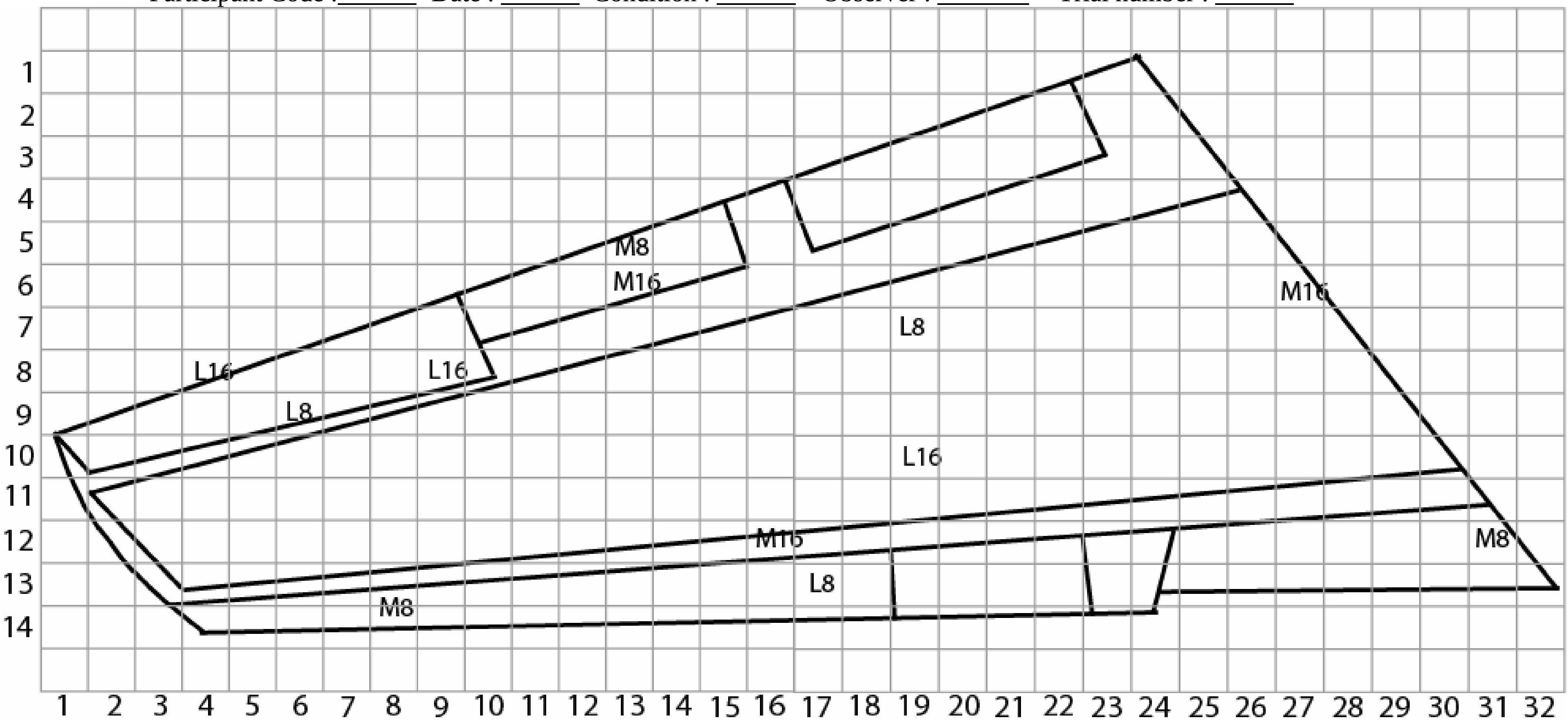
Comments/Interesting events:

____

____

Test Diagram – Day 3 High Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



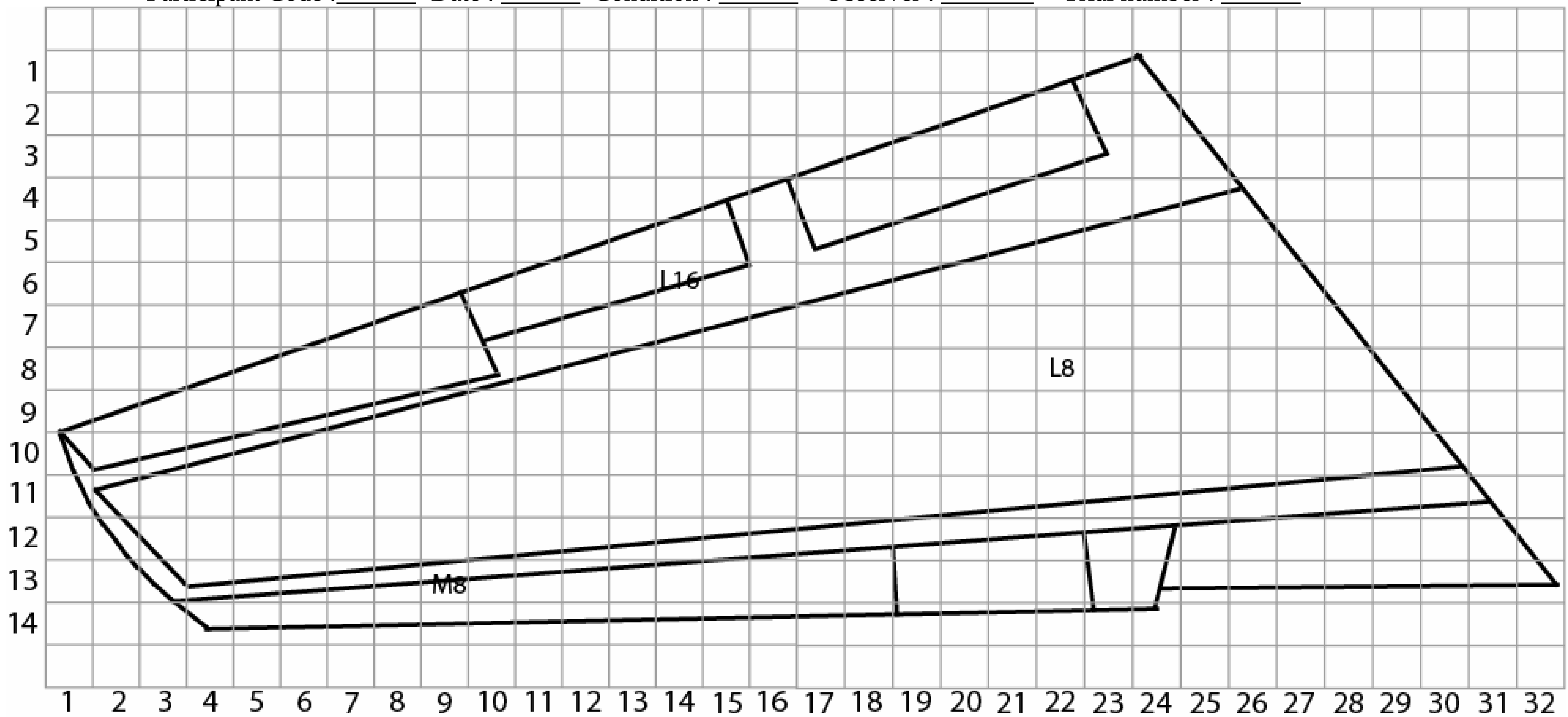
Visual inspection time: _______
Total inspection time: ______

Based on your **visual** inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________

Comments/Interesting events:

Test Diagram – Day 1 Low Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Visual inspection time: _______
Total inspection time: ______

Based on your **visual** inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________

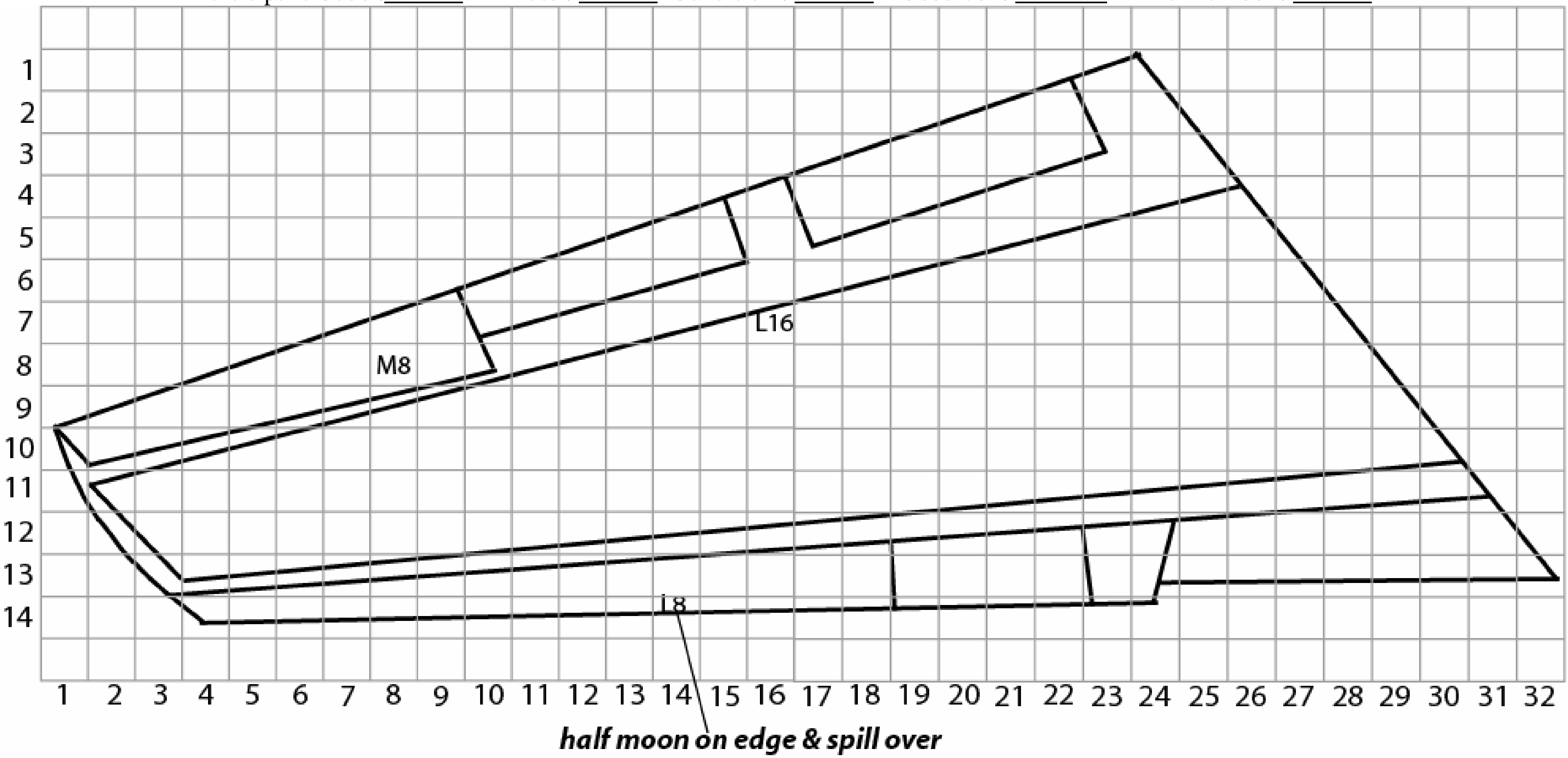
Comments/Interesting events:

____

____

Test Diagram – Day 2 Low Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Visual inspection time: _______
Total inspection time: ______

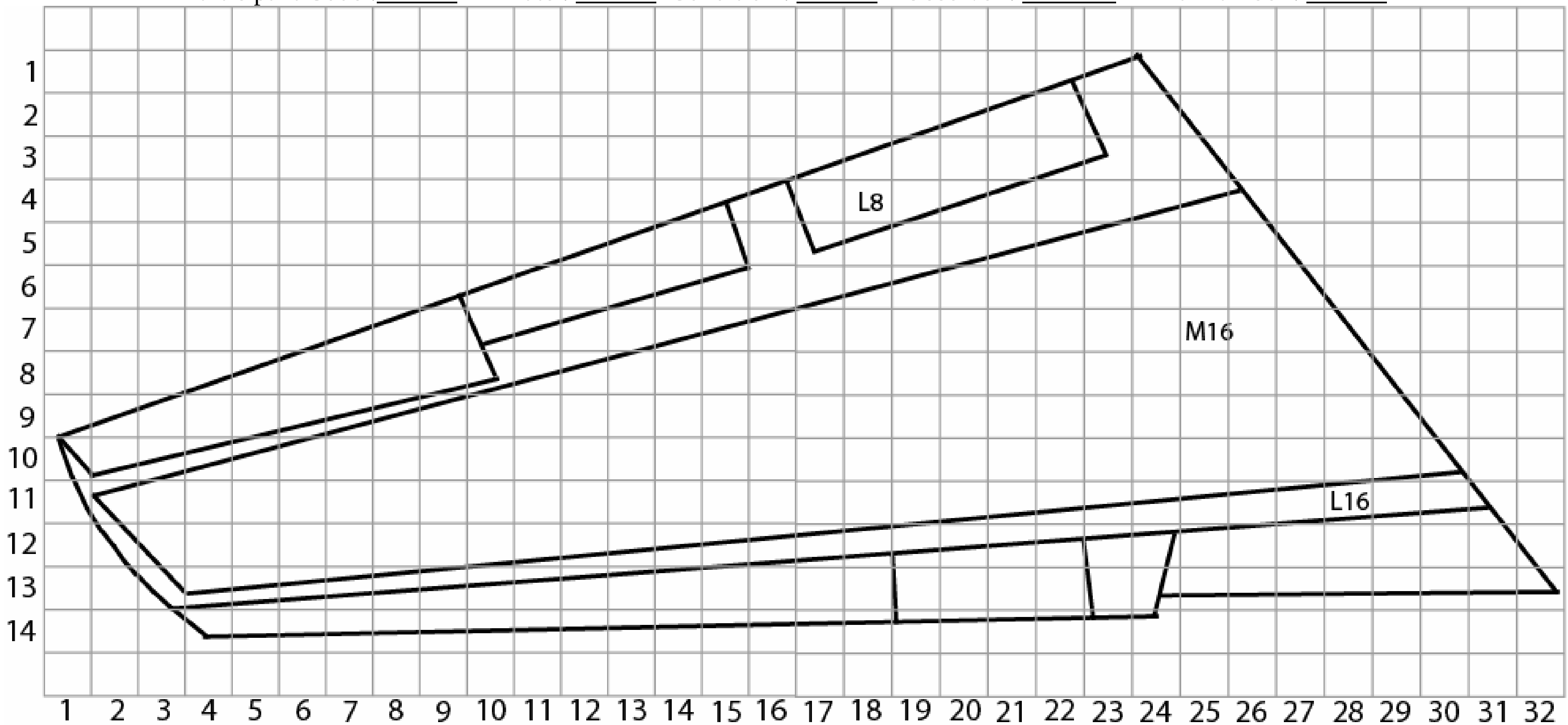
Based on your **visual** inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________
Comments/Interesting events:

____

____

Test Diagram – Day 3 Low Contamination Test

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Visual inspection time: _______
Total inspection time: ______

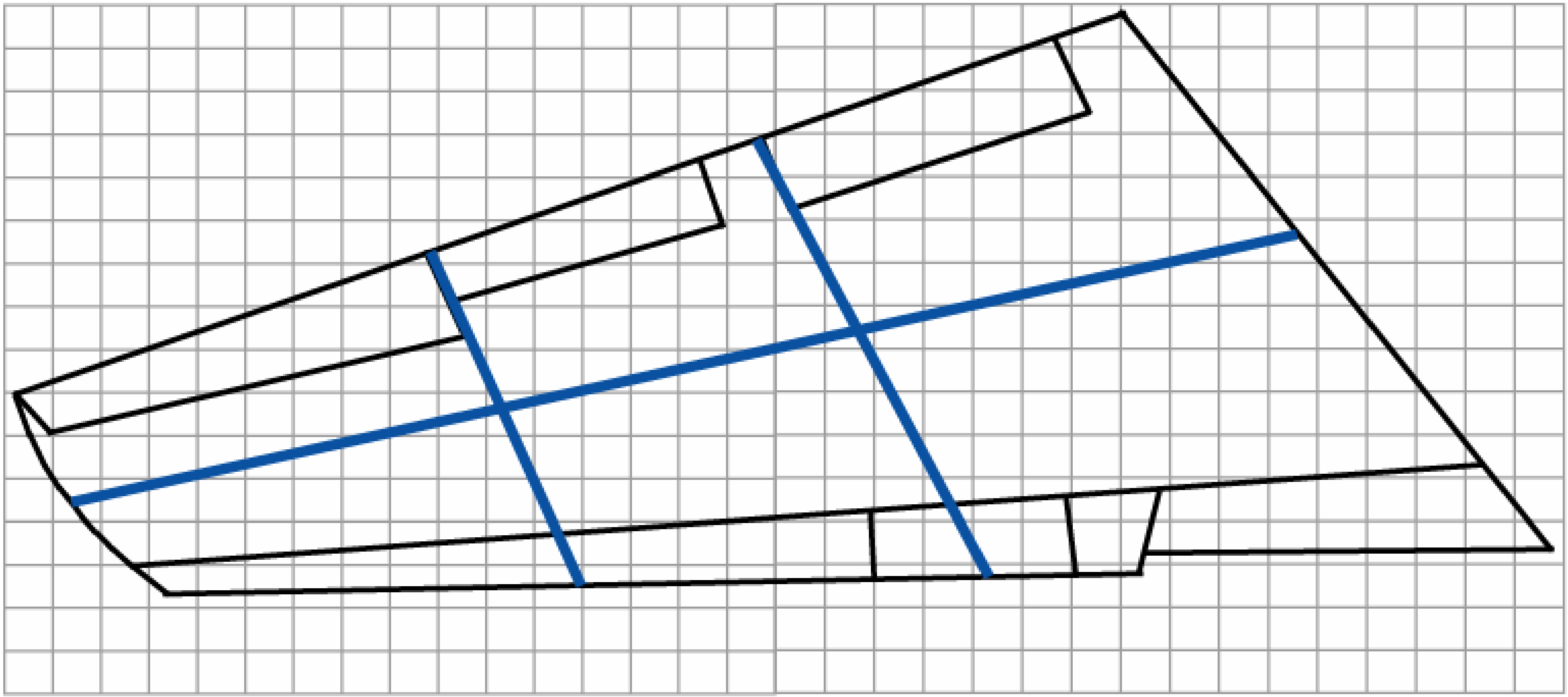
Based on your **visual** inspection, would you deice the aircraft? ________
Based on your **tactile** inspection, would you deice the aircraft? ________
Comments/Interesting events:

APPENDIX I

GIDS TEST ADMINISTRATION FORM

GIDS Test Administration Form

Participant Code :______ Date : ______ Condition : ______ Observer : _______ Trial number : ______



Inspection time: _______

Based on your inspection, would you deice the aircraft? ________

Comments/Interesting events:

____

____

____

Image number: __________

APPENDIX J

NASA TASK LOAD INDEX
(Electronic Format was used)

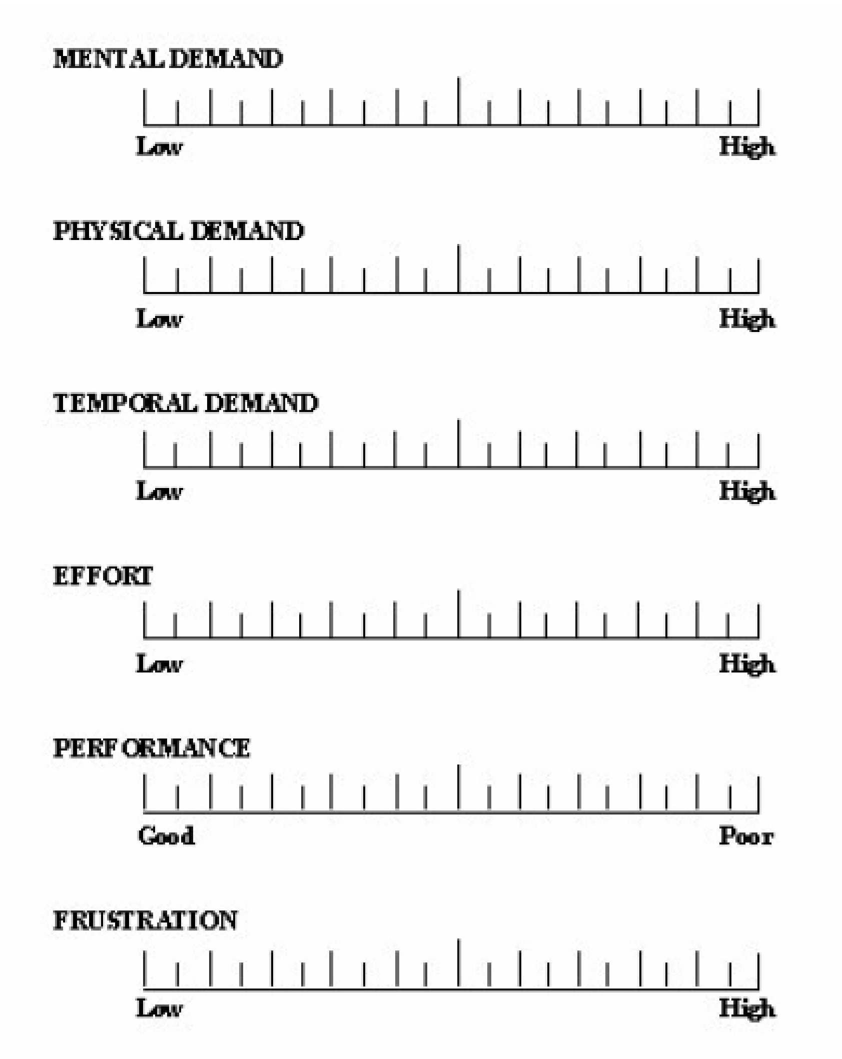
INSTRUCTIONS

We are interested not only in assessing your performance but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during different tasks. Please read the descriptions of the scales carefully. If you have a question about any of the scales in the table, please ask me about it. It is extremely important that they be clear to you. You may keep the descriptions with you for reference during the experiment.

RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Observer ID____________ Date _________________ Time _____________



MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

EFFORT

Low High

PERFORMANCE

Good Poor

FRUSTRATION

Low High

IMPORTANCE OF SCALE INSTRUCTIONS

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well, the workload must have been low, and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to **your** experience of workload in the task(s) that you just performed. Each pair of scale titles will appear separately on the screen. **Select the Scale Title that represents the more important contributor to workload for the Specific task(s) you performed in this experiment.**

Observer ID____________ Date _________________ Time _____________

For each row, please select the item that was most important to your experience of workload for the task you performed.

1	☐ **MENTAL DEMAND**	☐ **PHYSICAL DEMAND**
2	☐ **MENTAL DEMAND**	☐ **TEMPORAL DEMAND**
3	☐ **MENTAL DEMAND**	☐ **EFFORT**
4	☐ **MENTAL DEMAND**	☐ **PERFORMANCE**
5	☐ **MENTAL DEMAND**	☐ **FRUSTRATION**
6	☐ **PHYSICAL DEMAND**	☐ **TEMPORAL DEMAND**
7	☐ **PHYSICAL DEMAND**	☐ **EFFORT**
8	☐ **PHYSICAL DEMAND**	☐ **PERFORMANCE**
9	☐ **PHYSICAL DEMAND**	☐ **FRUSTRATION**
10	☐ **TEMPORAL DEMAND**	☐ **EFFORT**
11	☐ **TEMPORAL DEMAND**	☐ **PERFORMANCE**
12	☐ **TEMPORAL DEMAND**	☐ **FRUSTRATION**
13	☐ **EFFORT**	☐ **PERFORMANCE**
14	☐ **EFFORT**	☐ **FRUSTRATION**
15	☐ **PERFORMANCE**	☐ **FRUSTRATION**

Indice de la charge de travail de la NASA

INSTRUCTIONS

Nous sommes intéressés non seulement à évaluer votre performance, mais aussi à connaître votre expérience subjective de l’exécution des tâches qui vous ont été demandées. Voici comment nous allons nous y prendre pour obtenir cette information. En gros, nous nous pencherons sur la «charge de travail» que vous aurez ressentie. Le concept de charge de travail est difficile à définir avec précision, mais il est simple à comprendre. Divers facteurs influent sur notre expérience de la charge de travail : la tâche comme telle, nos sentiments à l’égard de notre performance, l’effort que l’on déploie, et le stress et la frustration que l’on ressent. La charge de travail associée à une tâche n’est pas toujours la même. Ainsi, elle peut s’alléger à mesure que l’on se familiarise avec la tâche, ou s’alourdir lorsqu’on passe d’une tâche à une autre, et il peut exister des versions faciles et difficiles d’une même tâche. Les composantes physiques de la charge de travail sont relativement faciles à conceptualiser et à évaluer. Mais il en va tout autrement des composantes mentales.

Comme la charge de travail est une expérience subjective, il n’existe pas de «règle» efficace pour mesurer la charge de travail associée à différentes activités. Une façon d’évaluer la charge de travail est de demander aux gens de décrire ce qu’ils ont ressenti en accomplissant une tâche. Comme la charge de travail est constituée de plusieurs facteurs, nous vous demanderons d’évaluer un par un ces facteurs, plutôt que de coter globalement la charge de travail. Les six échelles d’évaluation ont été conçues pour vous permettre d’indiquer comment vous vous êtes senti subjectivement au cours des différentes tâches. Veuillez lire attentivement la description de chacune des échelles. Si vous avez des questions sur l’une ou l’autre de ces descriptions, n’hésitez pas à me les poser. Il est extrêmement important qu’elles soient très claires pour vous. Vous pouvez garder ces descriptions avec vous pour pouvoir les consulter pendant l’expérience.

DÉFINITION DES ÉCHELLES D'ÉVALUATION		
Dimension	Cotes extrêmes	Description
EXIGENCE MENTALE	Faible/élevée	Quel niveau d'activité mentale et d'activité perceptive avez-vous dû déployer (p. ex., réfléchir, décider, calculer, se souvenir, examiner, chercher, etc.)? La tâche était-elle facile ou exigeante, simple ou complexe, astreignante ou agréable?
EXIGENCE PHYSIQUE	Faible/élevée	Quel niveau d'activité physique avez-vous dû déployer (p. ex., pousser, tirer, tourner, commander, activer, etc.)? La tâche était-elle facile ou exigeante, lente ou rapide, «mollo» ou fatigante, reposante ou pénible?
PRESSION TEMPORELLE	Faible/élevée	Dans quelle mesure vous sentiez-vous pressé par le temps, à cause de la cadence de la tâche? Ce rythme était-il lent et posé, ou rapide et frénétique?
EFFORT	Faible/élevé	Avez-vous dû travailler fort (mentalement et physiquement) pour atteindre votre niveau de performance?
PERFORMANCE	Bonne/médiocre	Dans quelle mesure pensez-vous avoir atteint les buts de la tâche, fixés par l'administrateur de tests (ou vous-même)? Dans quelle mesure êtes-vous satisfait de votre performance, par rapport à l'atteinte de ces buts?
FRUSTRATION	Faible/élevée	Dans quelle mesure vous sentiez-vous incertain, découragé, agacé, stressé et ennuyé, par opposition à sûr, heureux, content, détendu et satisfait de vous-même pendant que vous accomplissiez les tâches?

Observateur _________________ Date ____________________ Heure _____________

EXIGENCE MENTALE

Faible **Élevée**

EXIGENCE PHYSIQUE

Faible **Élevée**

PRESSION TEMPORELLE

Faible **Élevée**

EFFORT

Faible **Élevée**

PERFORMANCE

Bonne **Médiocre**

FRUSTRATION

Faible **Élevée**

IMPORTANCE DE BIEN SUIVRE LES INSTRUCTIONS

Pendant toute l'expérience, les échelles d'évaluation serviront à évaluer votre expérience subjective au cours des différentes tâches. Des échelles de ce genre sont extrêmement utiles, mais elles souffrent du fait que les gens ont tendance à les interpréter à leur manière. Par exemple, pour certaines personnes, l'exigence mentale ou la pression temporelle sont les aspects essentiels de la charge de travail, peu importe l'effort qu'ils ont déployé ou le niveau de performance qu'ils ont atteint. D'autres ont le sentiment que si leur performance est bonne, c'est que la charge de travail était forcément légère, et inversement. D'autres encore estiment que l'effort ou les sentiments de frustration sont les facteurs les plus importants de la charge de travail, et ainsi de suite. Des études antérieures ont déjà mis au jour toutes sortes de systèmes de valeurs. De plus, les facteurs qui contribuent à alourdir la charge de travail diffèrent d'une tâche à l'autre. Par exemple, la difficulté de certaines tâches peut tenir au fait qu'elles doivent être exécutées très rapidement. D'autres tâches peuvent paraître faciles ou difficiles en raison de l'intensité de l'effort mental ou physique exigé. D'autres encore semblent difficiles parce qu'il est impossible d'avoir une bonne performance, peu importe l'effort qu'on pourra déployer.

La fiche d'évaluation que l'on vous demande de remplir a été conçue par la NASA. Elle sert à évaluer l'importance relative que vous accordez à six facteurs dans la lourdeur de la charge de travail ressentie. La procédure est simple : on vous présente une série de paires de dimensions (par exemple, Effort vs Exigence mentale) et vous devez choisir quelle dimension a été plus importante que l'autre dans **votre** expérience de la charge de travail associée à la tâche (ou aux tâches) que vous venez d'exécuter. Chaque paire de dimensions apparaîtra une après l'autre sur l'écran. **Vous devez choisir chaque fois la dimension qui a le plus contribué à votre expérience subjective de la charge de travail associée à la tâche (ou aux tâches) que vous avez accomplie(s) au cours de l'expérience.**

Observateur ________________ Date ___________________ Heure ____________

À chaque rangée, choisissez la dimension qui a le plus contribué à votre expérience subjective de la charge de travail associée à la tâche que vous avez accomplie.

1	☐	**EXIGENCE MENTALE**	☐	**EXIGENCE PHYSIQUE**
2	☐	**EXIGENCE MENTALE**	☐	**PRESSION TEMPORELLE**
3	☐	**EXIGENCE MENTALE**	☐	**EFFORT**
4	☐	**EXIGENCE MENTALE**	☐	**PERFORMANCE**
5	☐	**EXIGENCE MENTALE**	☐	**FRUSTRATION**
6	☐	**EXIGENCE PHYSIQUE**	☐	**PRESSION TEMPORELLE**
7	☐	**EXIGENCE PHYSIQUE**	☐	**EFFORT**
8	☐	**EXIGENCE PHYSIQUE**	☐	**PERFORMANCE**
9	☐	**EXIGENCE PHYSIQUE**	☐	**FRUSTRATION**
10	☐	**PRESSION TEMPORELLE**	☐	**EFFORT**
11	☐	**PRESSION TEMPORELLE**	☐	**PERFORMANCE**
12	☐	**PRESSION TEMPORELLE**	☐	**FRUSTRATION**
13	☐	**EFFORT**	☐	**PERFORMANCE**
14	☐	**EFFORT**	☐	**FRUSTRATION**
15	☐	**PERFORMANCE**	☐	**FRUSTRATION**

APPENDIX K

POST-TEST QUESTIONNAIRE

PARTICIPANT ID	DATE

SECTION I
VISUAL AND TACTILE INSPECTIONS

Stressors

Compared to your everyday inspections, how did the following stressors affect your ability to find ice on the wing? *Circling a 0 would indicate that it had no affect.*

1	Temperature	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
2	Noise	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
3	Wind	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
4	Time Pressure	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*

Wing and Ice Used in Study

Compared to your everyday inspections, how did the following affect your ability to find ice on the wing? *Circling a 0 would indicate that it had no affect.*

5	Ice Thickness	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
6	Ice Roughness	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
7	Ice Edge	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
8	Inability to Scratch the Ice	*Made it Extremely*	-1 -2 -3 0 1 2 3	*Made it Extremely*

		Easy		*Difficult*
9	Lighting	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
10	Viewing Angle	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
11	Viewing Distance	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
12	Wing Color	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
13	Fluid	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*

Physiological Effects

14	Rate the level of fatigue that you experienced during the course of the study.	*Extremely Fatigued*	-1 -2 -3 0 1 2 3	*Not Fatigued at All*
15	Rate how much you believe fatigue affected your performance.	*Greatly Decreased Performance*	-1 -2 -3 0 1 2 3	*No Effect*

16. Please list any other physiological effects that may have affected your inspection.

Realism

17	Rate the realism of the procedures employed for the inspection of the **High Contamination wing** in this study compared to post deicing procedures in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
18	Rate the realism of the ice samples on the **High Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
19	Rate the realism of the overall **High Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
20	Rate the realism of the procedures employed for inspection of the **Low Contamination wing** in this study compared to post deicing procedures in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
21	Rate the realism of the ice samples on the **Low Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
22	Rate the realism of the overall **Low Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*

23. If you believe that any of the above properties have been unrealistic, what were they and why?

____

____

____

____

PLEASE GO ON TO THE NEXT PAGE

PARTICIPANT ID	DATE

SECTION II
GIDS I INSPECTIONS

Stressors

Compared to your everyday inspections, how did the following stressors affect your ability to find ice on the wing? *Circling a 0 would indicate that it had no affect.*

24	Temperature	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
25	Noise	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
26	Wind	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*
27	Time Pressure	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	*Made it Extremely Difficult*

Physiological Effects

28	Rate the level of fatigue that you experienced during the course of the study.	*Extremely Fatigued*	-1 -2 -3 0 1 2 3	*Not Fatigued at All*
29	Rate how much you believe fatigue affected your performance.	*Greatly Decreased Performance*	-1 -2 -3 0 1 2 3	*No Effect*

30. Please list anything else that may have affected your inspection.

____

____

____

____

Realism

31	Rate the realism of the ice samples on the **High Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
32	Rate the realism of the overall **High Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
33	Rate the realism of the ice samples on the **Low Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
34	Rate the realism of the overall **Low Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*

35. If you believe that any of the above properties have been unrealistic, what were they and why?

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Visual Inspections

36	How does GIDS 1 compare with **visual inspections** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
37	How would using GIDS 1 in the field to conduct **visual inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
38	How would using GIDS 1 in the field to conduct **visual inspection** affect the safety of **the airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
39	Would you recommend replacing current **visual inspections** with inspections using this device?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Tactile Inspections

40	How does GIDS 1 compare with **tactile inspections** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
41	How would using GIDS 1 in the field to conduct **tactile inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
42	How would using GIDS 1 in the field to conduct **tactile inspections** affect the safety **airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
43	Would you recommend replacing current **tactile inspections** with inspections using GIDS 1?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Visual and Tactile Inspections Combined

44	How does GIDS 1 compare with **both visual and tactile inspections together** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
45	How would using GIDS 1 in the field to replace **both visual and tactile inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
46	How would using GIDS 1 in the field to conduct **both visual and tactile inspections** affect the **safety of the airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
47	Would you recommend replacing **current visual and tactile inspections** with inspections using GIDS 1?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Training and Use of GIDS I

48	How confident were you in the accuracy of inspection using GIDS 1?	*Extremely Unsure*	-1 -2 -3 0 1 2 3	*Extremely Confident*

49	Did you feel adequately trained on this GIDS device?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

If not, why?

50	Have you ever used a GIDS device during the course of your employment?	*Please circle one*	YES NO	

51. If yes, how does this device compare to one you have used in the field?

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52. If you believe anything was unrealistic, what was it and why was it unrealistic?

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53. How else might you use GIDS I in the field?

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54. Any other comments?

PLEASE GO ON TO THE NEXT PAGE

PARTICIPANT ID	DATE

SECTION III
GIDS II INSPECTIONS

Stressors

Compared to your everyday inspections, how did the following stressors affect your ability to find ice on the wing? *Circling a 0 would indicate that it had no affect.*

55	Temperature	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	***Made it Extremely Difficult***
56	Noise	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	***Made it Extremely Difficult***
57	Wind	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	***Made it Extremely Difficult***
58	Time Pressure	*Made it Extremely Easy*	-1 -2 -3 0 1 2 3	***Made it Extremely Difficult***

Physiological Effects

59	Rate the level of fatigue that you experienced during the course of the study.	*Extremely Fatigued*	-1 -2 -3 0 1 2 3	*Not Fatigued at All*
60	Rate how much you believe fatigue affected your performance.	*Greatly Decreased Performance*	-1 -2 -3 0 1 2 3	*No Effect*

61. Please list anything else that may have affected your inspection.

Realism

62	Rate the realism of the ice samples on the **High Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
63	Rate the realism of the overall **High Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
64	Rate the realism of the ice samples on the **Low Contamination wing** compared to residual ice seen after post deicing in the real world.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*
65	Rate the realism of the overall **Low Contamination wing** sample compared to post deicing conditions in the field.	*Extremely Unrealistic*	-1 -2 -3 0 1 2 3	*Extremely Realistic*

66. If you believe that any of the above properties have been unrealistic, what were they and why?

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Visual Inspections

67	How does GIDS 2 compare with **visual inspections** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
68	How would using GIDS 2 in the field to conduct **visual inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
69	How would using GIDS 2 in the field to conduct **visual inspection** affect the safety of **the airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
70	Would you recommend replacing current **visual inspections** with inspections using GIDS 2?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Tactile Inspections

71	How does GIDS 2 compare with **tactile inspections** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
72	How would using GIDS 2 in the field to conduct **tactile inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
73	How would using GIDS 2 in the field to conduct **tactile inspections** affect the safety of **the airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
74	Would you recommend replacing current **tactile inspections** with inspections using GIDS 2?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Visual and Tactile Inspections Combined

75	How does GIDS 2 compare with **both visual and tactile inspections together** for finding ice?	*Absolutely Worse*	-1 -2 -3 0 1 2 3	*Absolutely Better*
76	How would using GIDS 2 in the field to replace **both visual and tactile inspections** affect **your personal safety**?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
77	How would using GIDS 2 in the field to conduct **both visual and tactile inspections** affect the **safety of the airplane** you inspect?	*Absolutely More Dangerous*	-1 -2 -3 0 1 2 3	*Absolutely Safer*
78	Would you recommend replacing **current visual and tactile inspections** with inspections using GIDS 2?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

Training and Use of GIDS II

79	How confident were you in the accuracy of inspection using GIDS 2?	*Extremely Unsure*	-1 -2 -3 0 1 2 3	*Extremely Confident*

80	Did you feel adequately trained on this GIDS device?	*Absolutely Not*	-1 -2 -3 0 1 2 3	*Absolutely Yes*

81. If not, why?

82	Have you ever used a GIDS device during the course of your employment?		YES NO	

83. If yes, how does this device compare to one you have used in the field?

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84. If you believe anything was unrealistic, what was it and why was it unrealistic?

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85. How else might you use GIDS II in the field?

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86. Any other comments?

THIS IS THE END OF THE QUESTIONNAIRE
THANK YOU!

APPENDIX L

STATISTICAL TERMS

Statistical Significance is analyzed by conducting a variety of different types of statistical tests. In order to decide if an analysis results in statistical significance, a few crucial elements are needed. These elements are briefly described below.

Mean:
The sum of all data observations divided by the number of observations.

Standard deviation:
Each data point in the collected data sample differs from the mean by an amount called the **deviation** (***d***). Each ***d*** value is found by subtraction (keeping the sign as + or -), then square each deviation, add all the d^2 values (to get the sum of squares of the deviations, shortened to the **sum of squares**) and divide this by ***n*-1**, where ***n*** is the number of data points in our sample. We can then obtain the **standard deviation,** which is the square root of the variance. Simply put, the standard deviation tells us how far a typical member of the sample is from the mean value of that sample.

Alpha level (.05):
This represents the statistical significance level. It is the probability of making what is called a Type I error. A Type I error occurs when you reject the null hypothesis when it should not be rejected. For example, in this study a null hypothesis might be that all four methods of inspection are equal in the amount of ice patches they should detect. The alternative hypothesis is that they are not all equal. The alpha level criterion was set at .05 in order to state whether the null hypothesis is rejected or not. An alpha of .05 means that there is a 5 out of 100 chance that the statistical difference found between the groups was from a sampling error and not an actual difference between the groups.

Parametric test:
A statistical test in which statistical assumptions are made about the distribution of observed data.

ANOVA:
A parametric type of statistical test that analyzes two or more group means by looking at the variance that appears in the data. An F ratio is calculated and compared against a table of critical values to determine whether your results are significant or not.

Non-Parametric tests:
Used when the statistical assumptions are not satisfied for parametric tests. Example of a non-parametric test that is used in this study is the Friedman mean rank test.

Friedman mean rank test
This test is an alternative to the repeated measures ANOVA, when the assumption of normality or equality of variance is not met. This, like many non-parametric tests, uses the ranks of the data rather than their raw values to calculate the statistic.

APPENDIX M

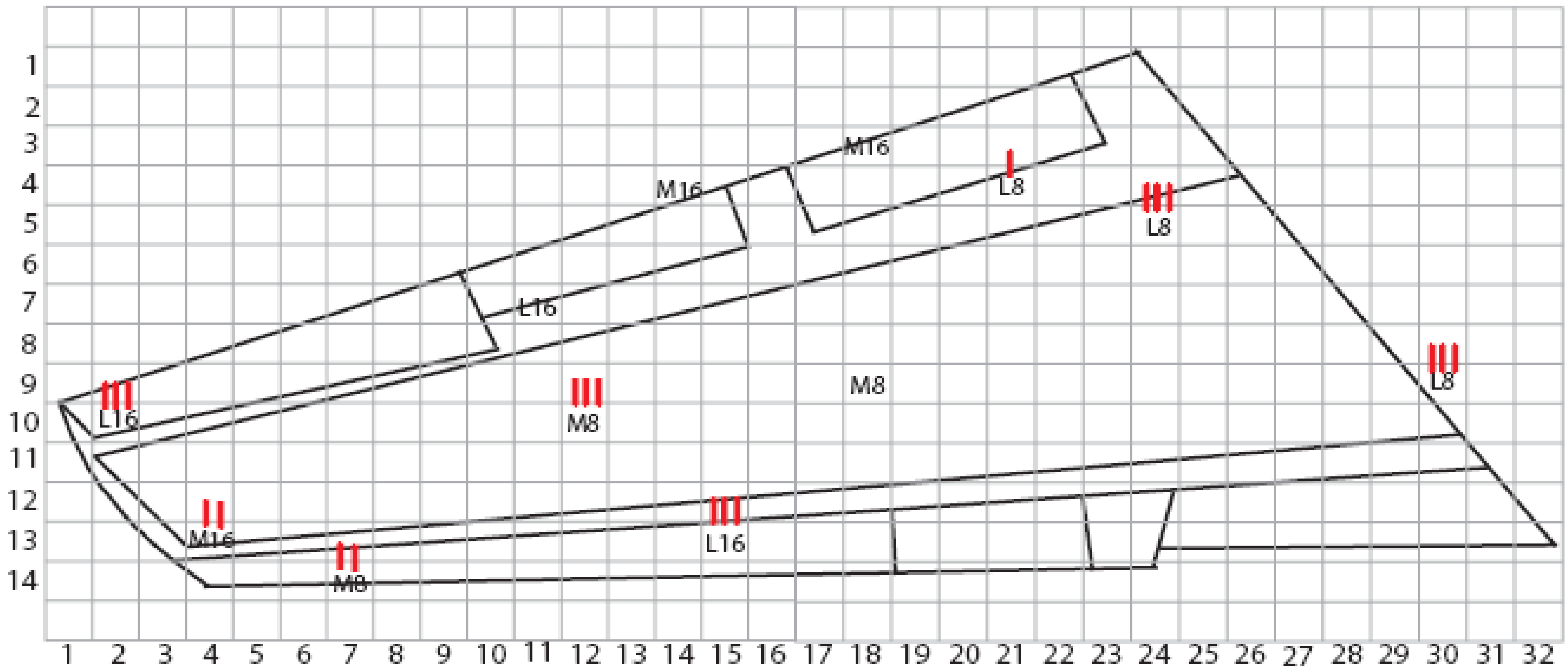
LOCATION ANALYSIS DIAGRAMS

Visual

Test Diagram - Day 1
High Contamination Test

	L - Low (.3 -.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)

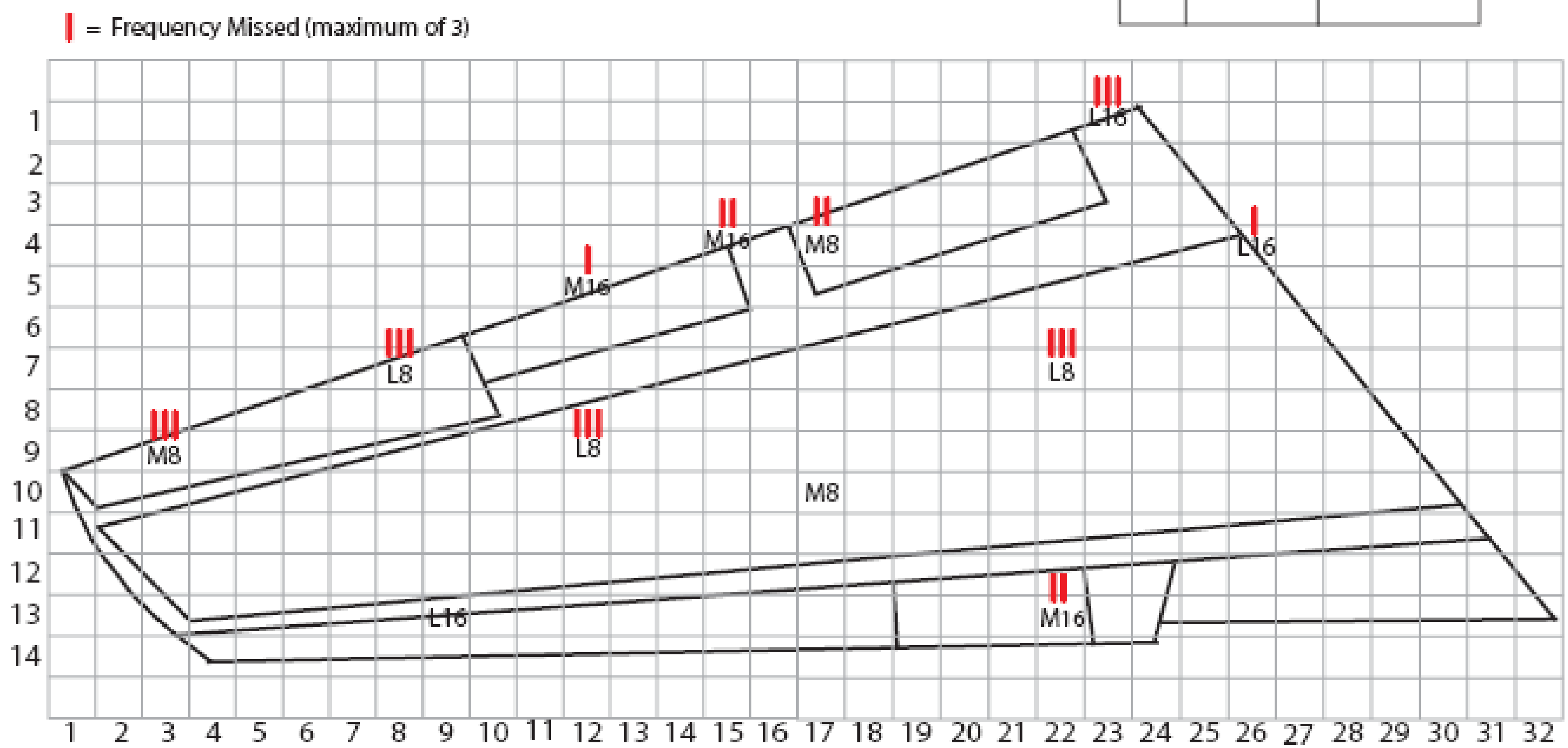


Leading Edge

Visual

Test Diagram - Day 2
High Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

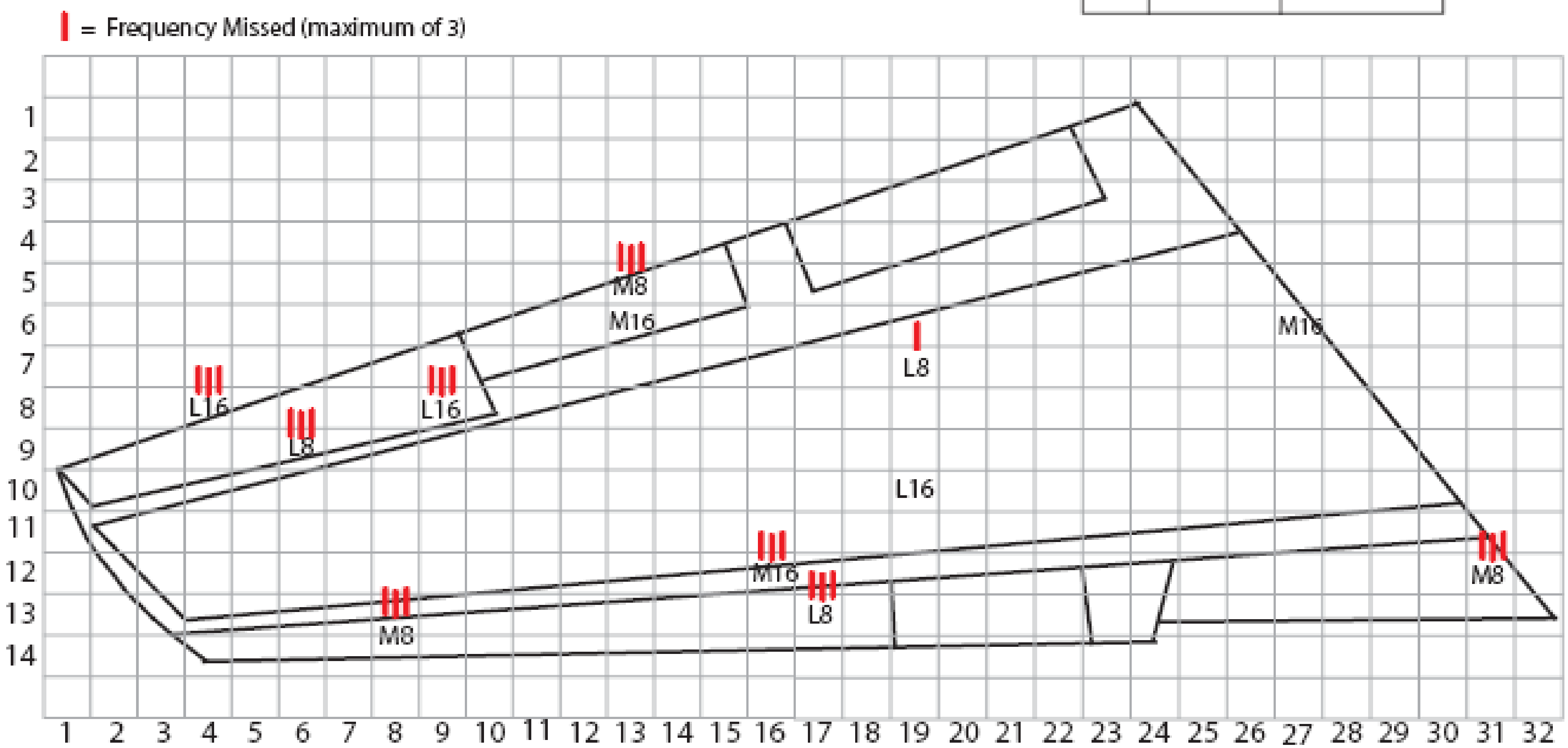


Leading Edge

Visual

Test Diagram - Day 3
High Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16



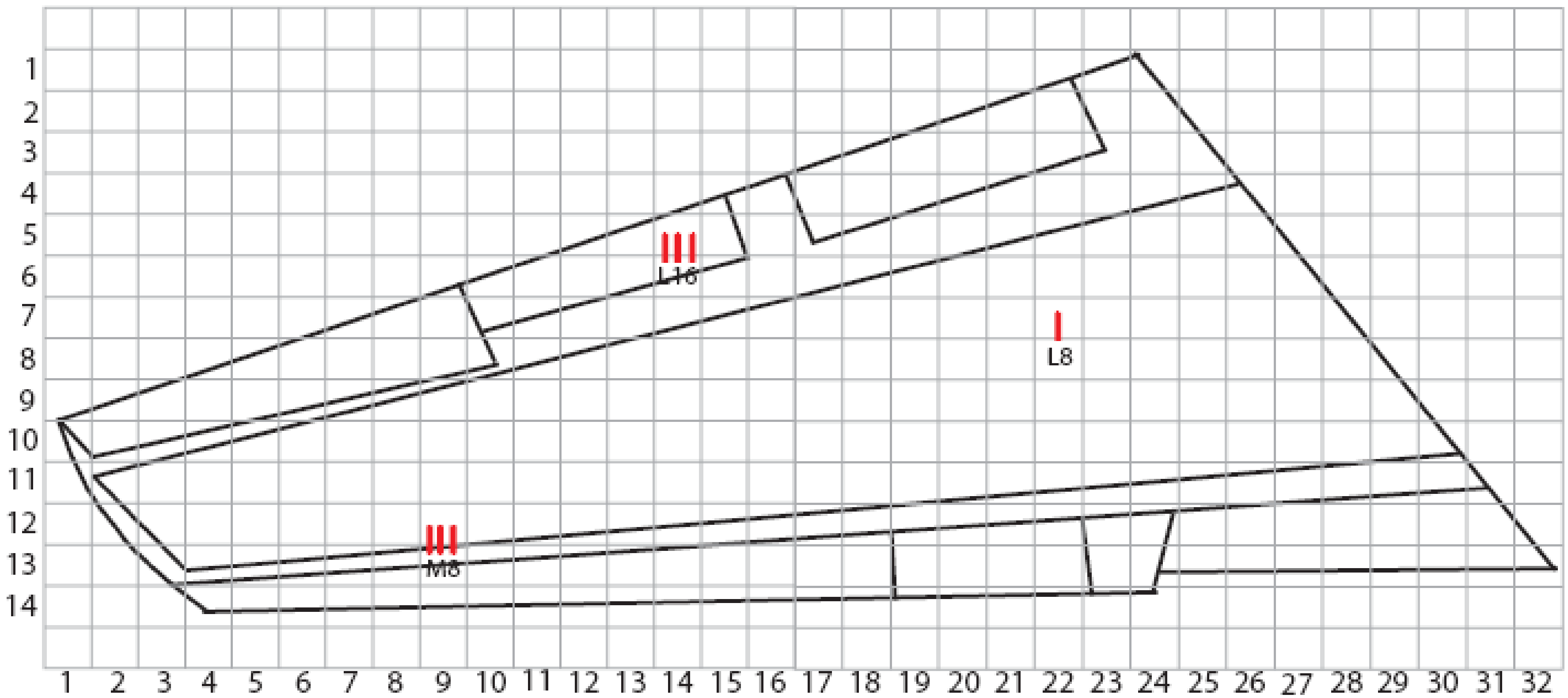
Leading Edge

Visual

Test Diagram - Day 1
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)

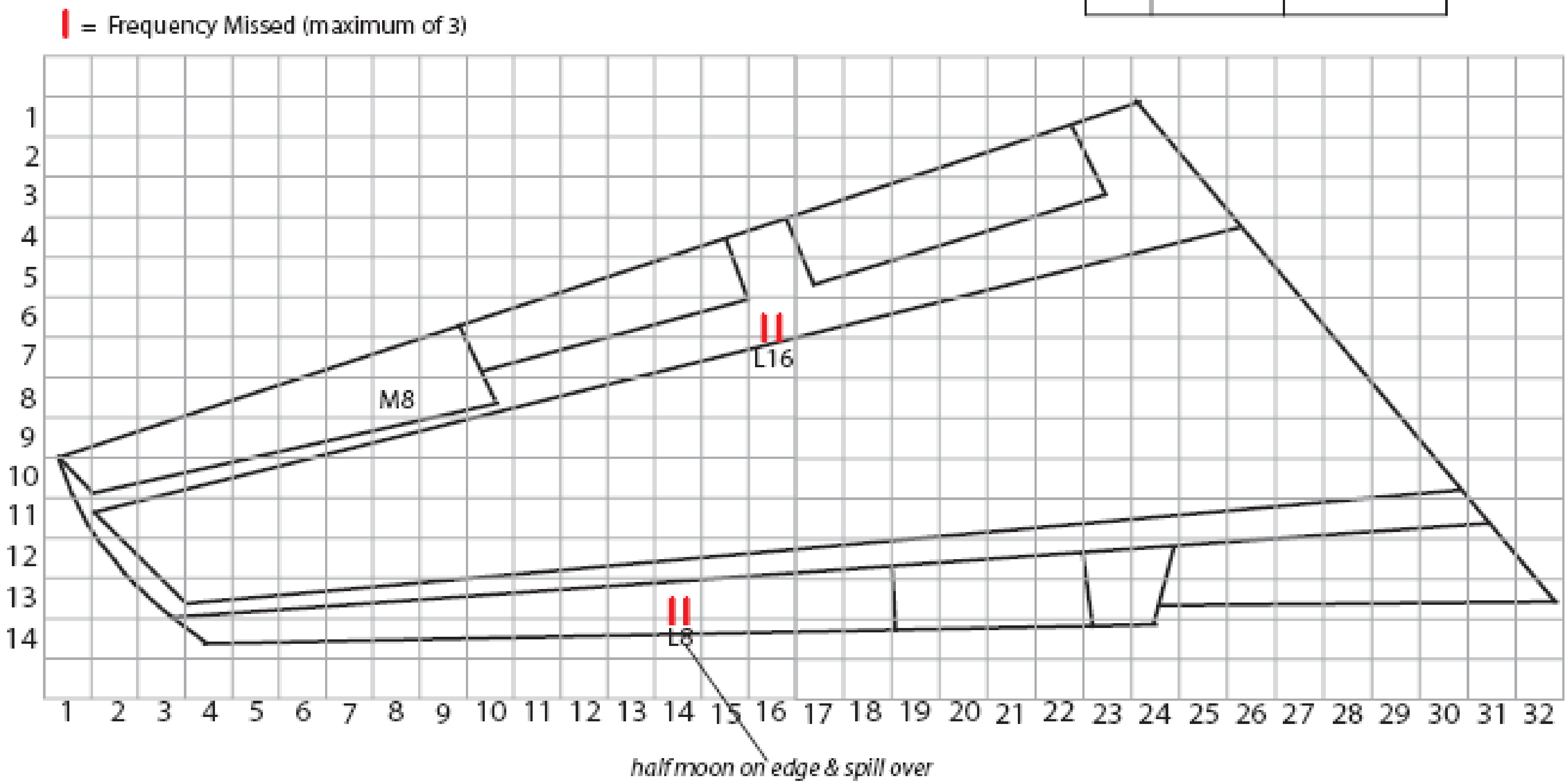


Leading Edge

Visual

Test Diagram - Day 2
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

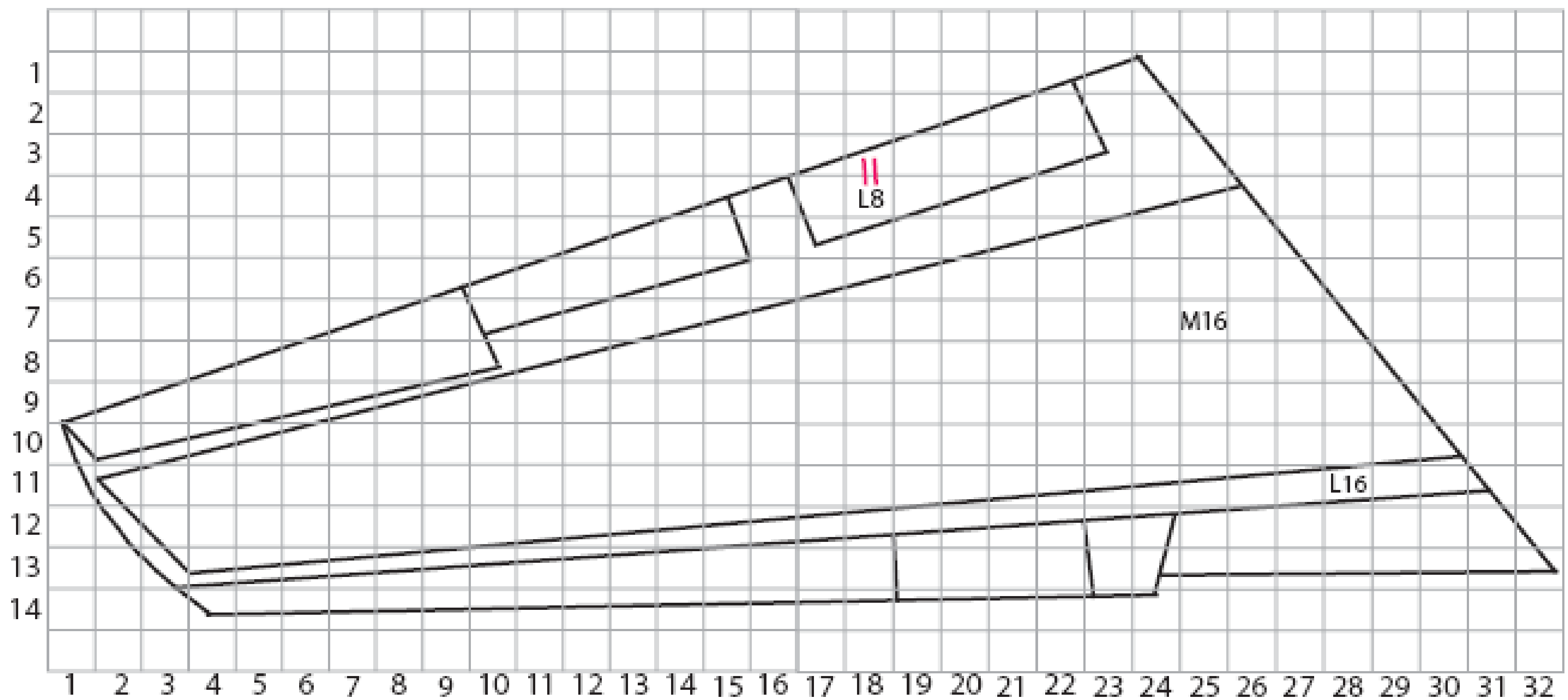


Visual

Test Diagram - Day 3
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



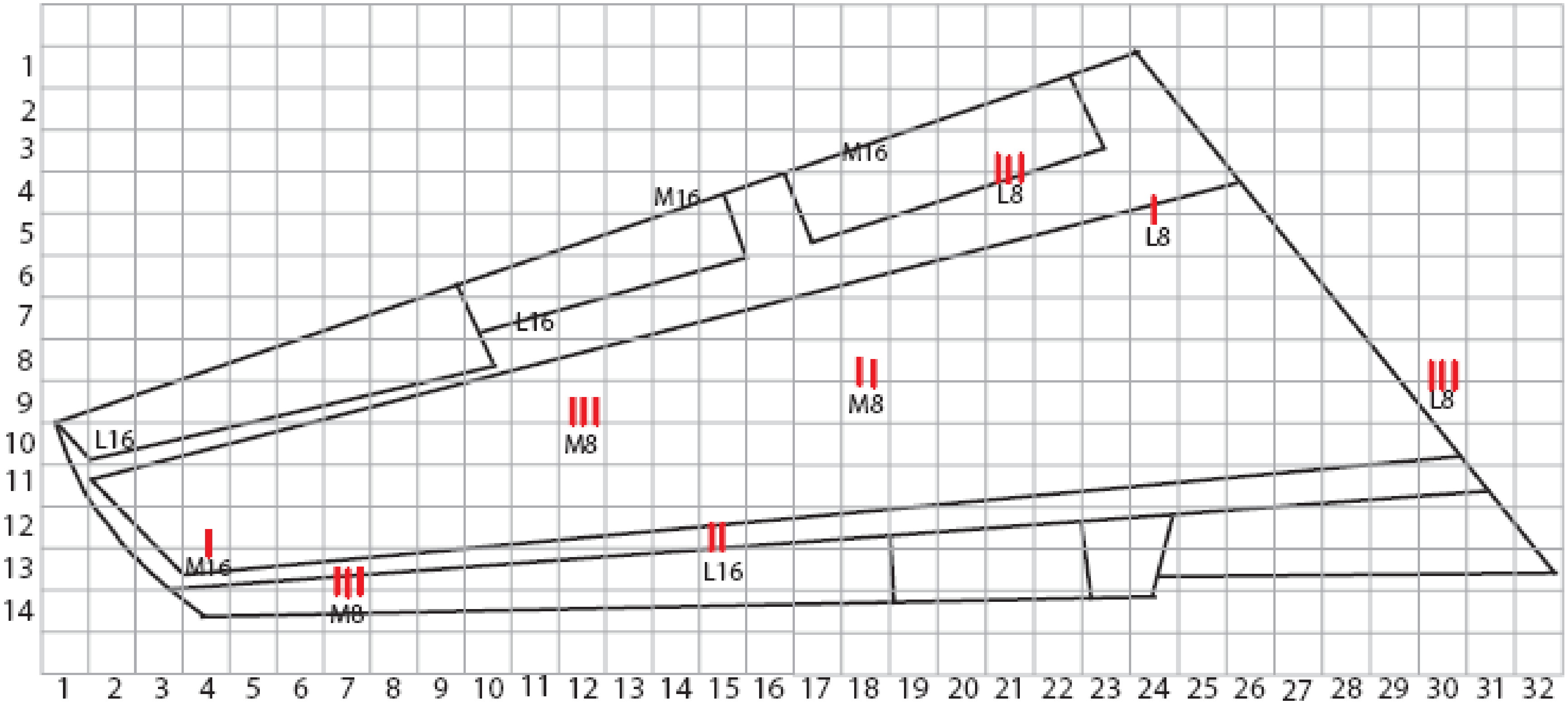
Leading Edge

Tactile

Test Diagram - Day 1
High Contamination Test

	L - Low (.3-.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



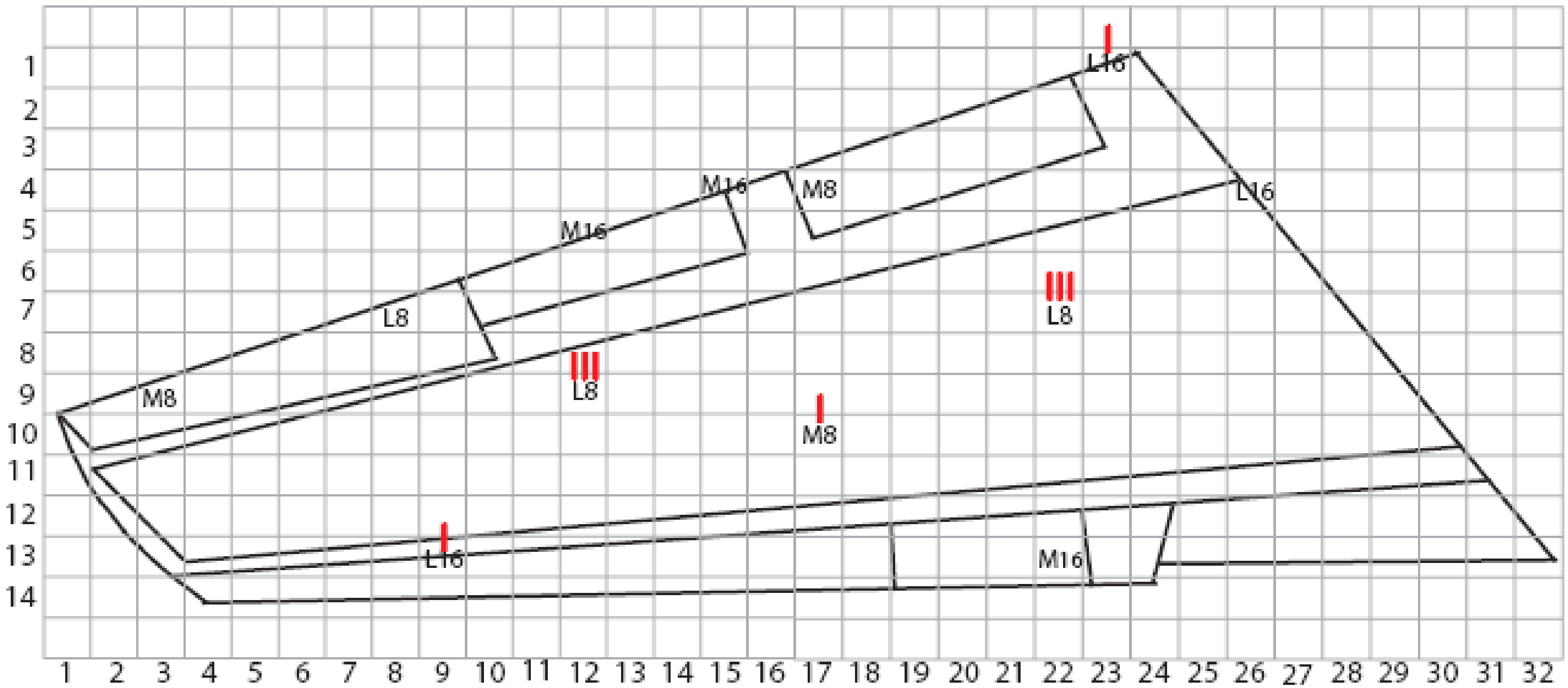
Leading Edge

Tactile

Test Diagram - Day 2
High Contamination Test

	L - Low (.3-.5mm)	M - Moderate (.6-.8mm)
8in	L8	M8
16in	L16	M16

= Frequency Missed (maximum of 3)

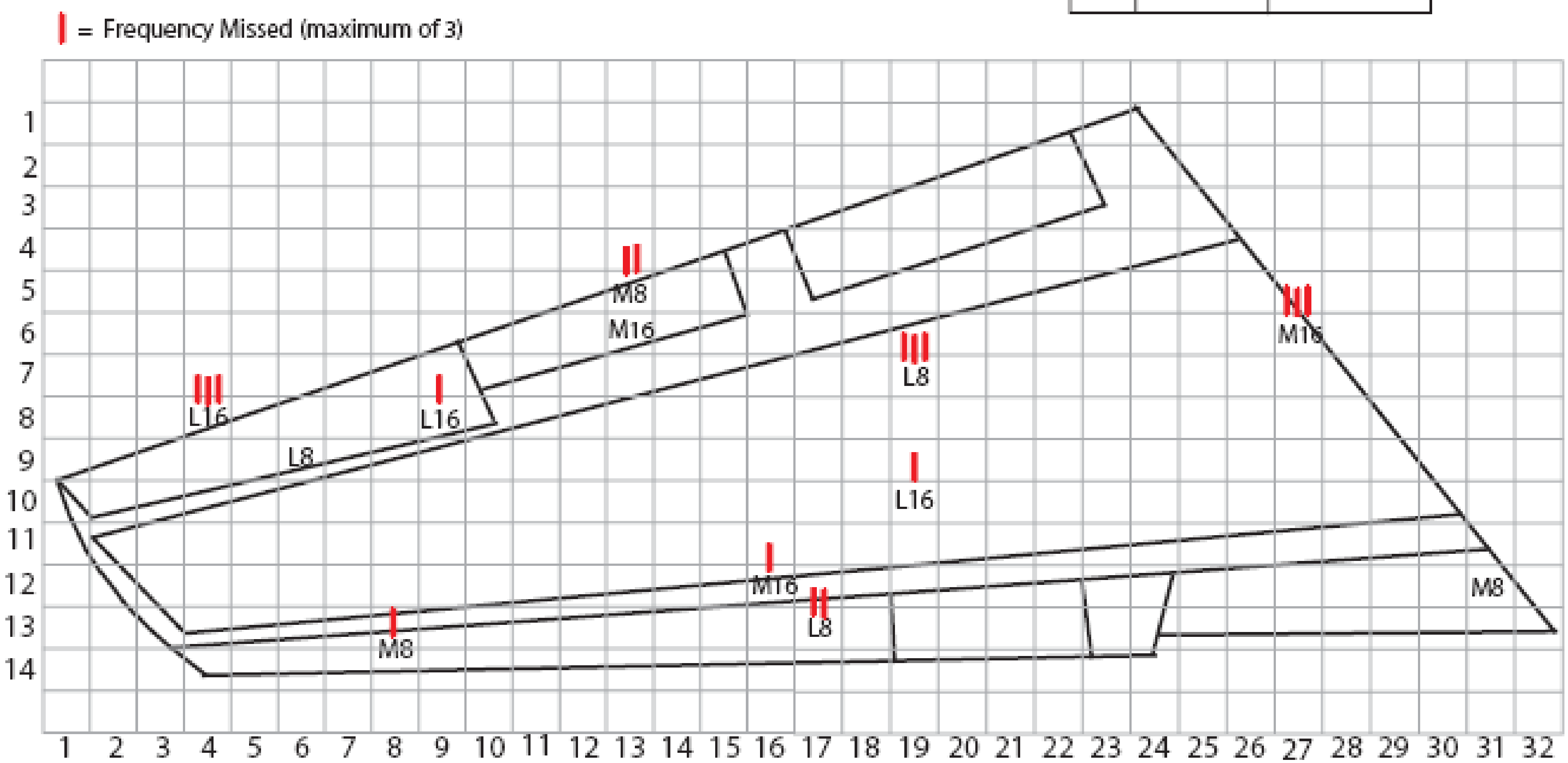


Leading Edge

Tactile

Test Diagram - Day 3
High Contamination Test

	L - Low (.3-.5mm)	M - Moderate (.6-.8mm)
8in	L8	M8
16in	L16	M16



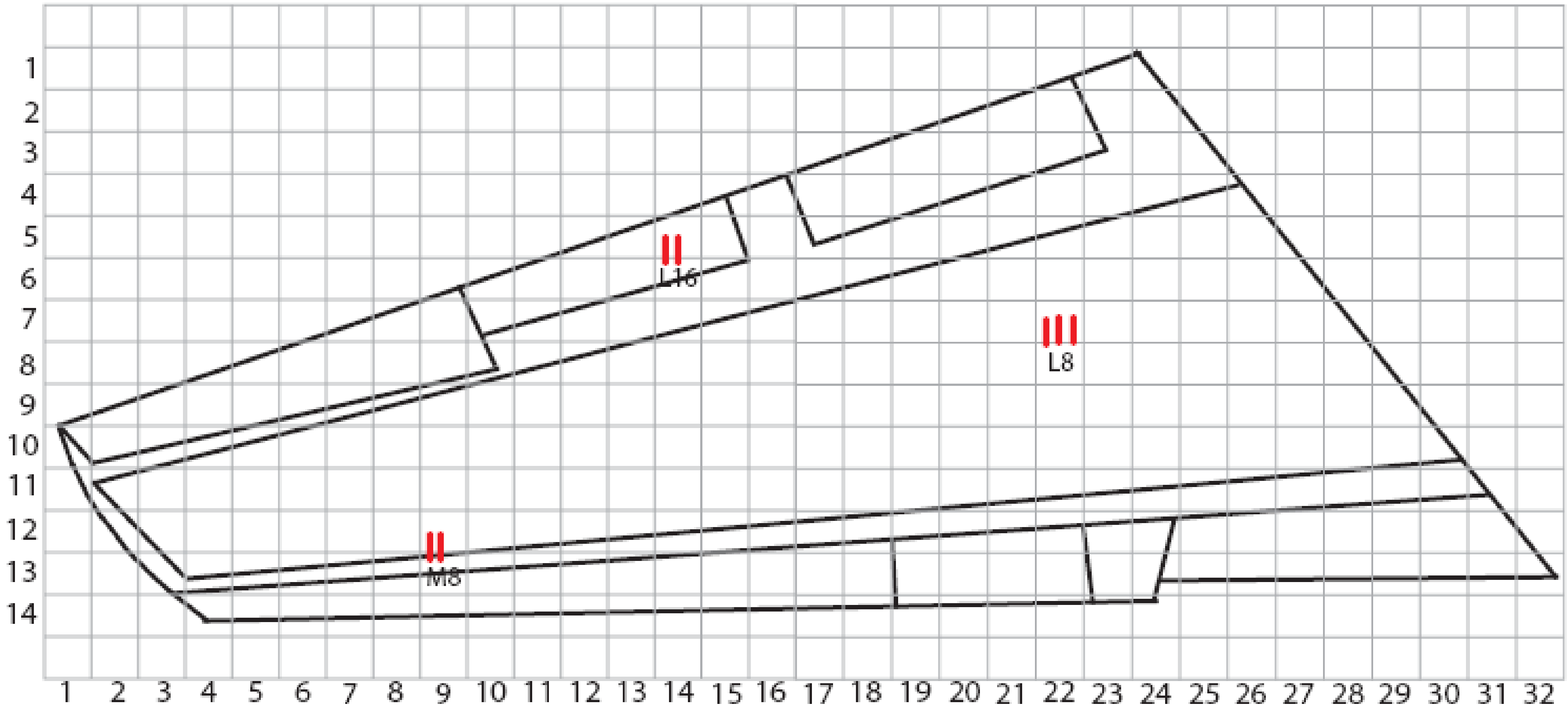
Leading Edge

Tactile

Test Diagram - Day 1
Low Contamination Test

	L - Low (.3-.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

▌ = Frequency Missed (maximum of 3)



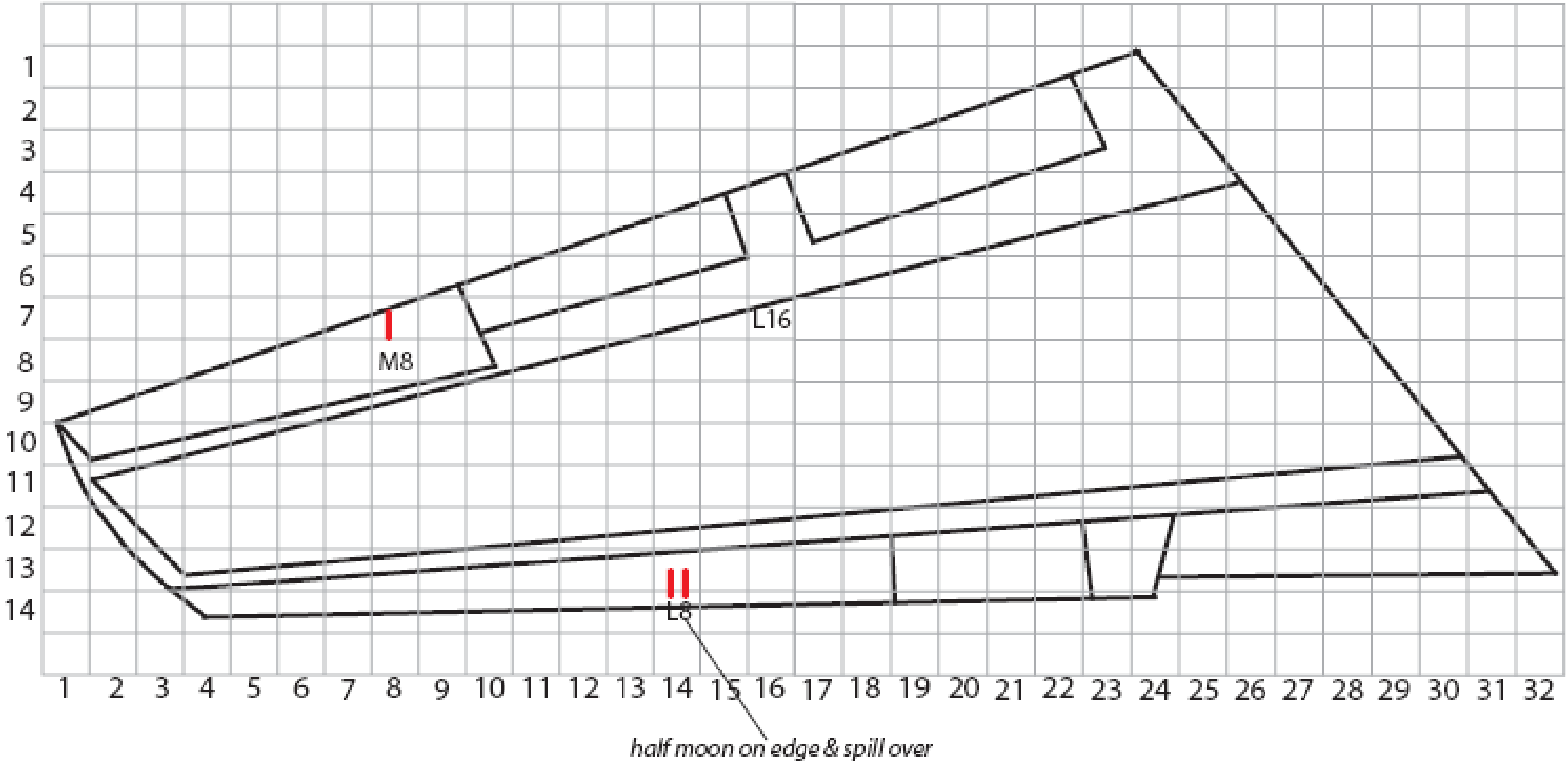
Leading Edge

Tactile

Test Diagram - Day 2
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

= Frequency Missed (maximum of 3)

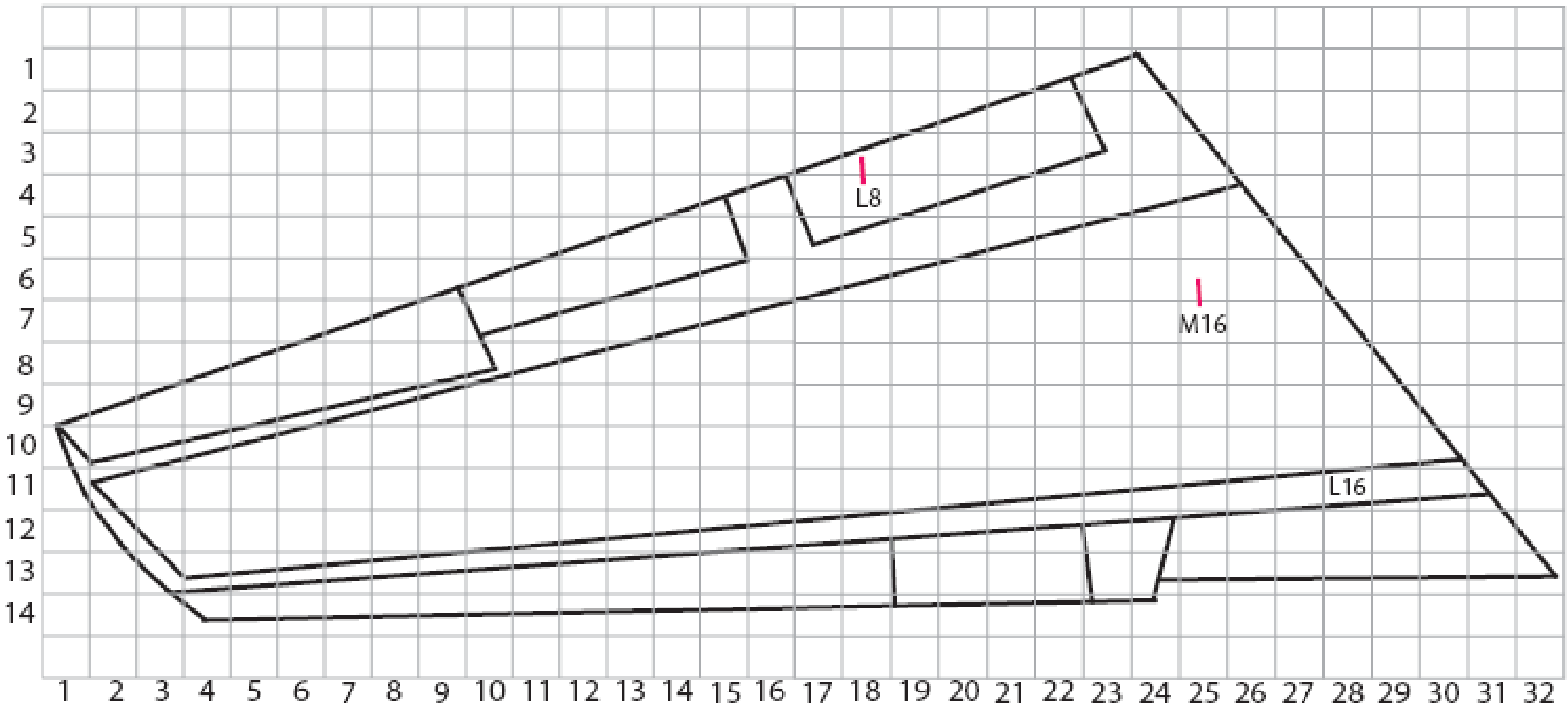


Tactile

Test Diagram - Day 3
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)

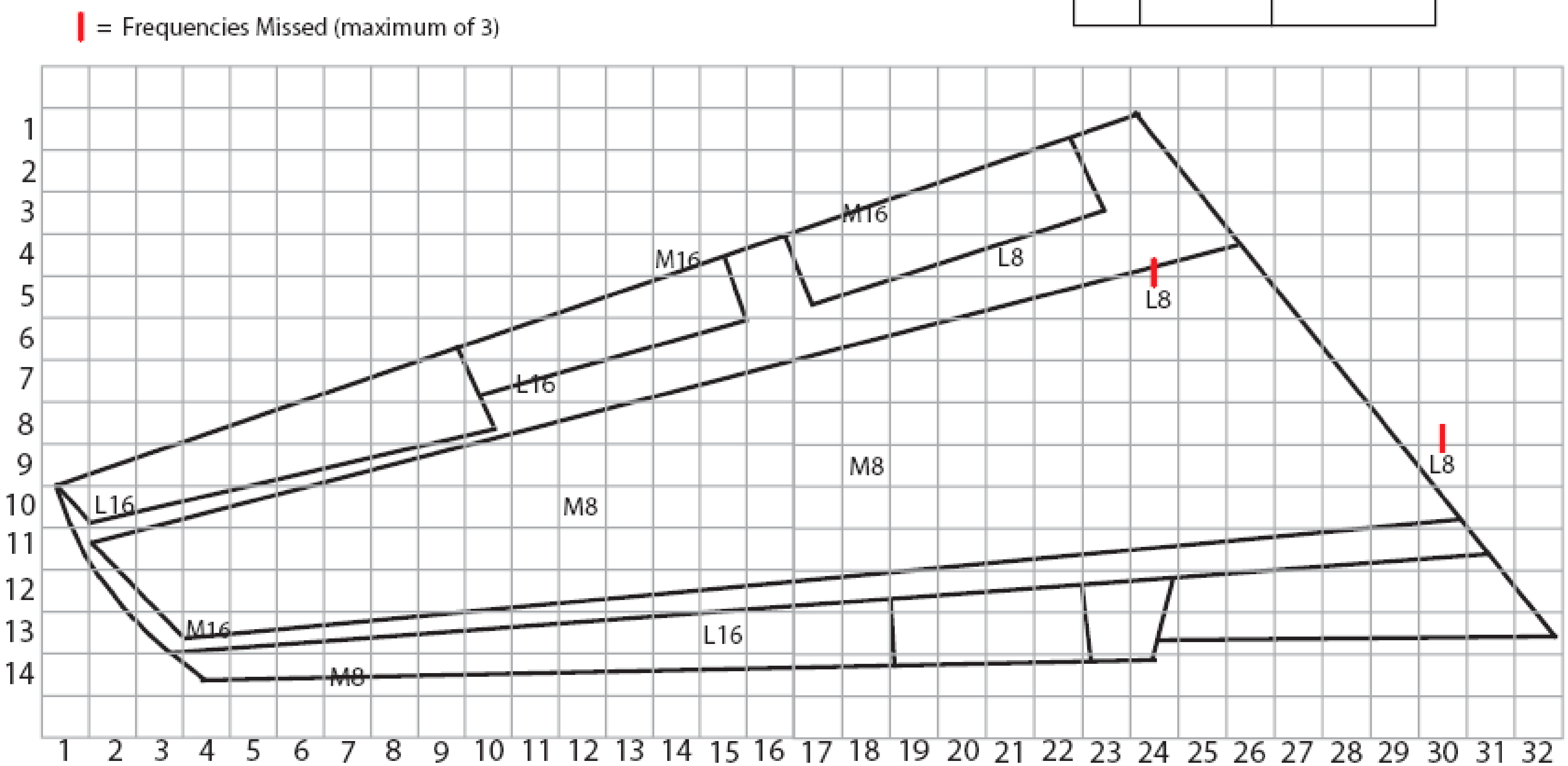


Leading Edge

GIDS 1

Test Diagram - Day 1
High Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16



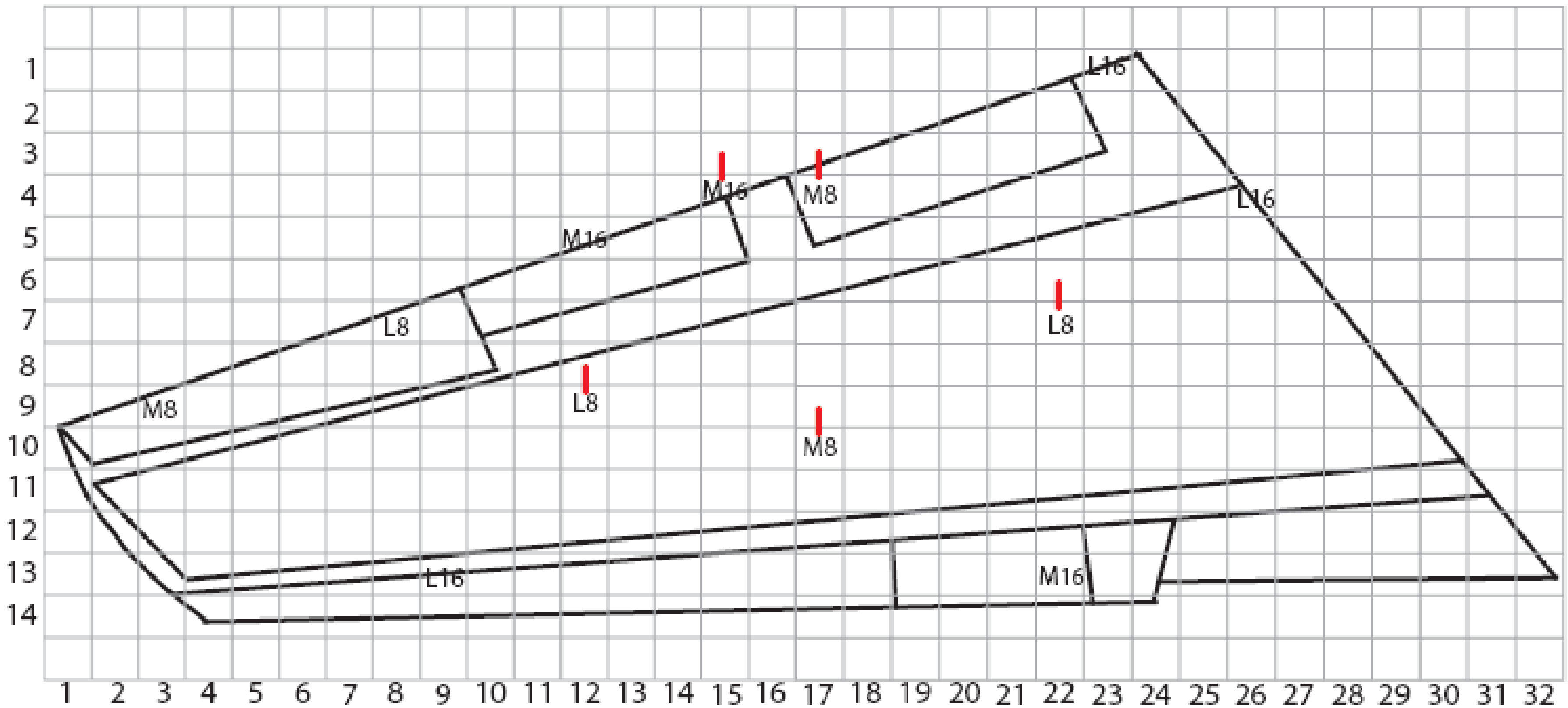
Leading Edge

GIDS 1

Test Diagram - Day 2
High Contamination Test

	L - Low (.3 -.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

= Frequency Missed (maximum of 3)



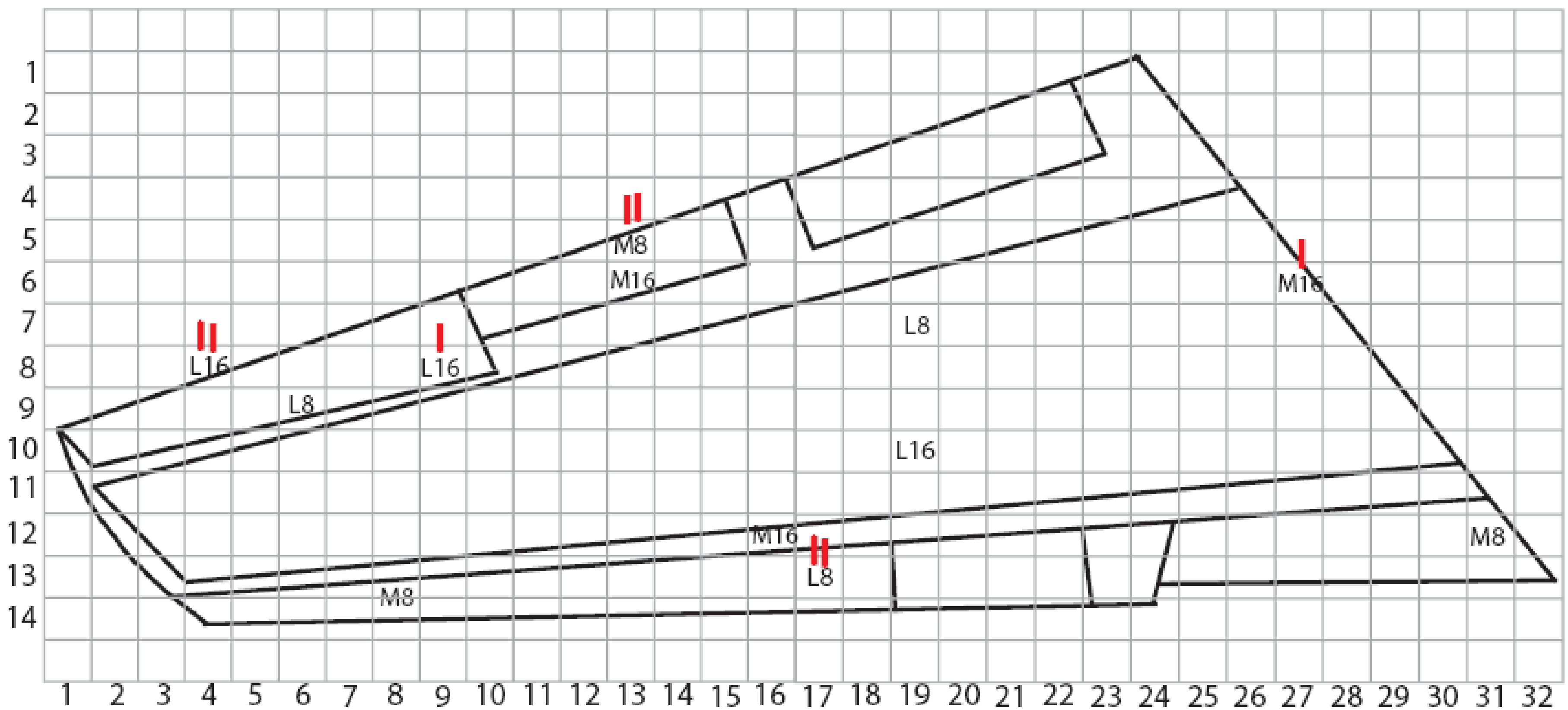
Leading Edge

GIDS 1

Test Diagram - Day 3
High Contamination Test

	L - Low (.3-.5mm)	M - Moderate (.6 -.8mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



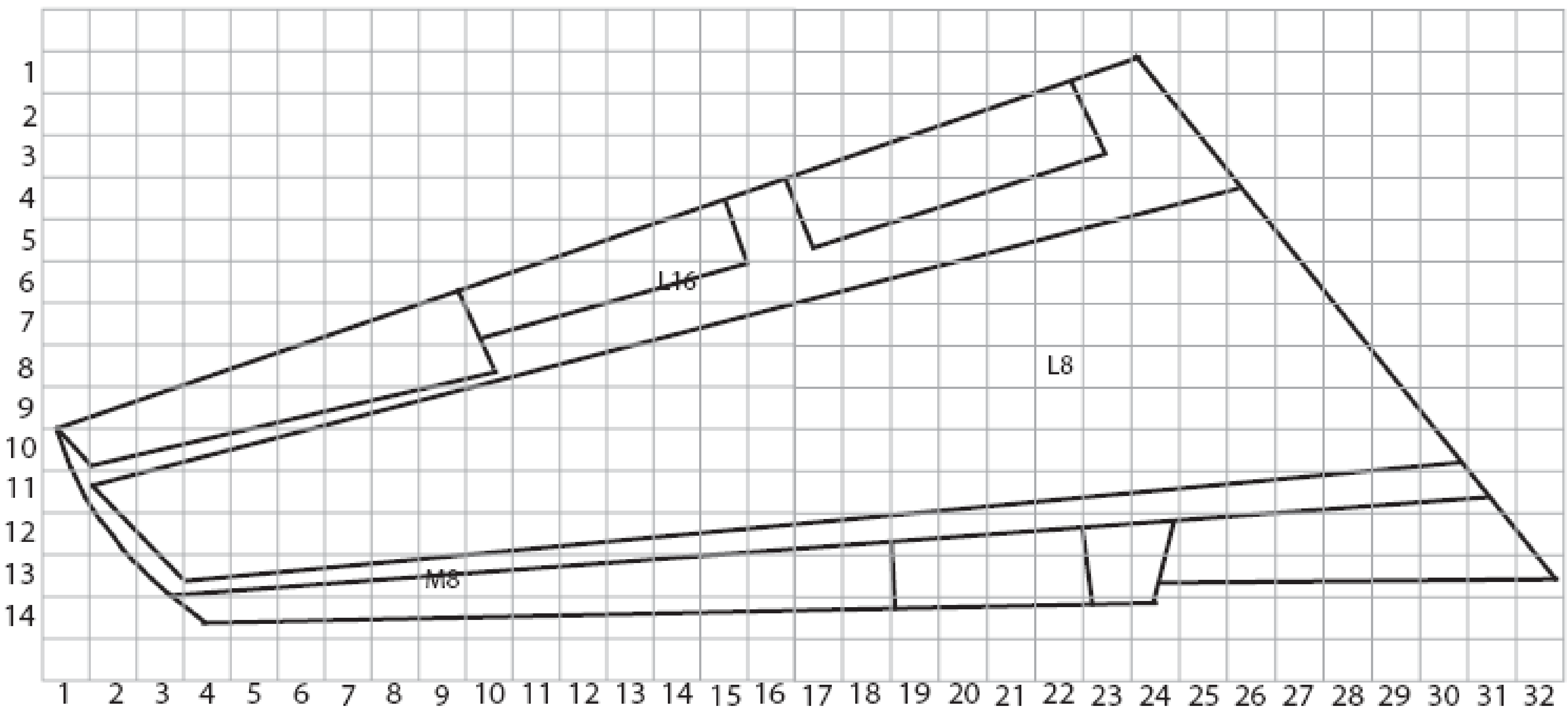
Leading Edge

GIDS 1

Test Diagram - Day 1
Low Contamination Test

	L - Low (.3-.5 mm)	M - Moderate (.6-.8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



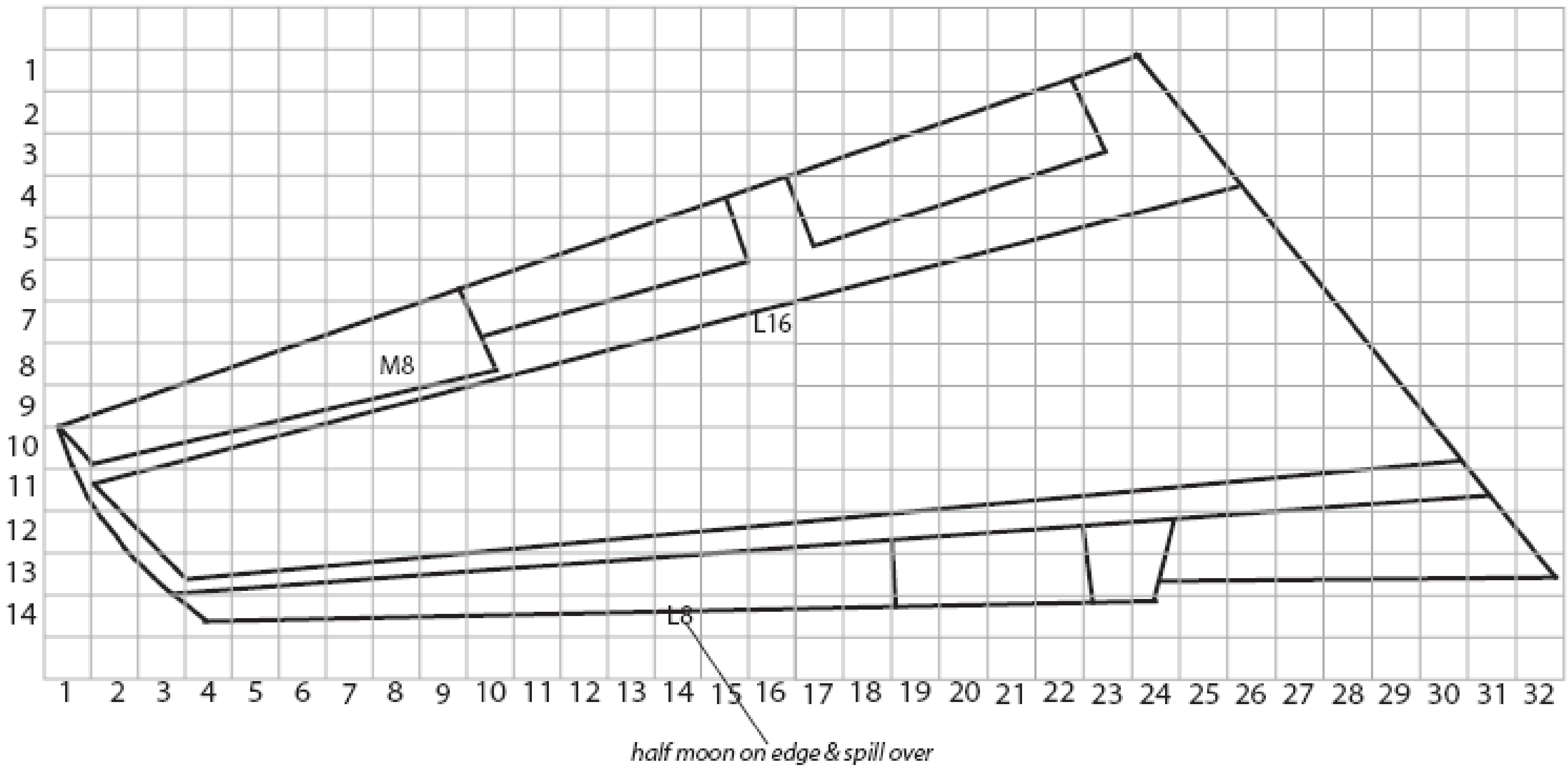
Leading Edge

GIDS 1

Test Diagram - Day 2
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

= Frequency Missed (maximum of 3)

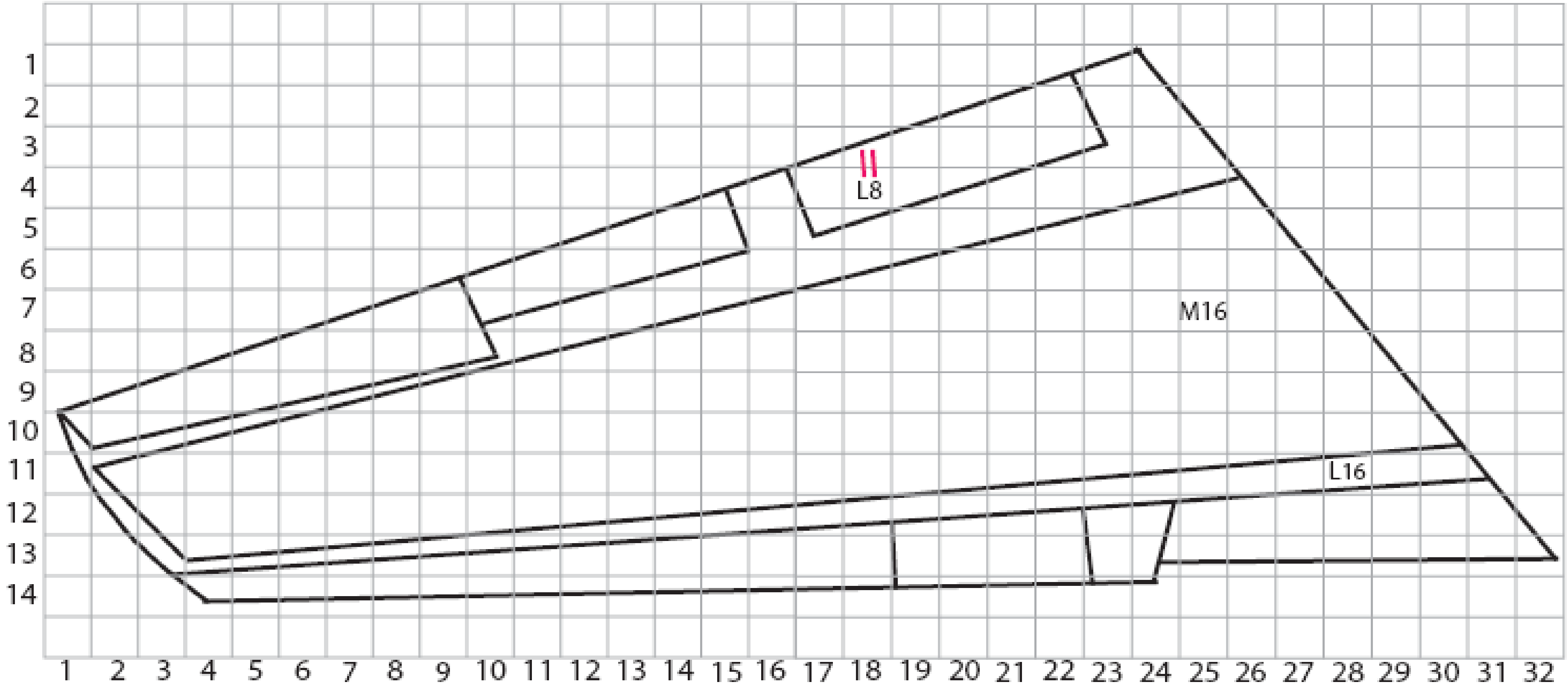


GIDS 1

Test Diagram - Day 3
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

= Frequency Missed (maximum of 3)



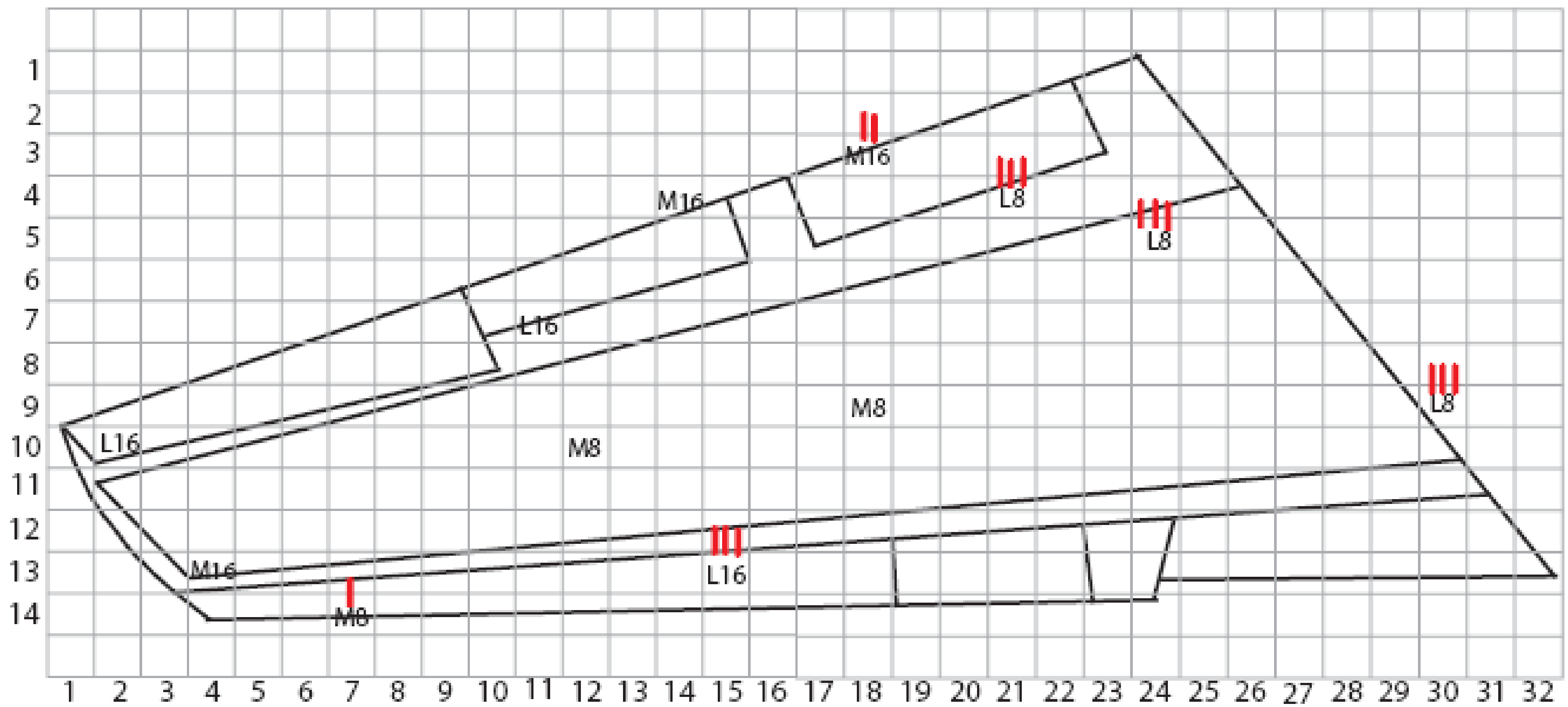
Leading Edge

GIDS 2

Test Diagram - Day 1
High Contamination Test

	L - Low (.3-.5 mm)	M - Moderate (.6-.8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



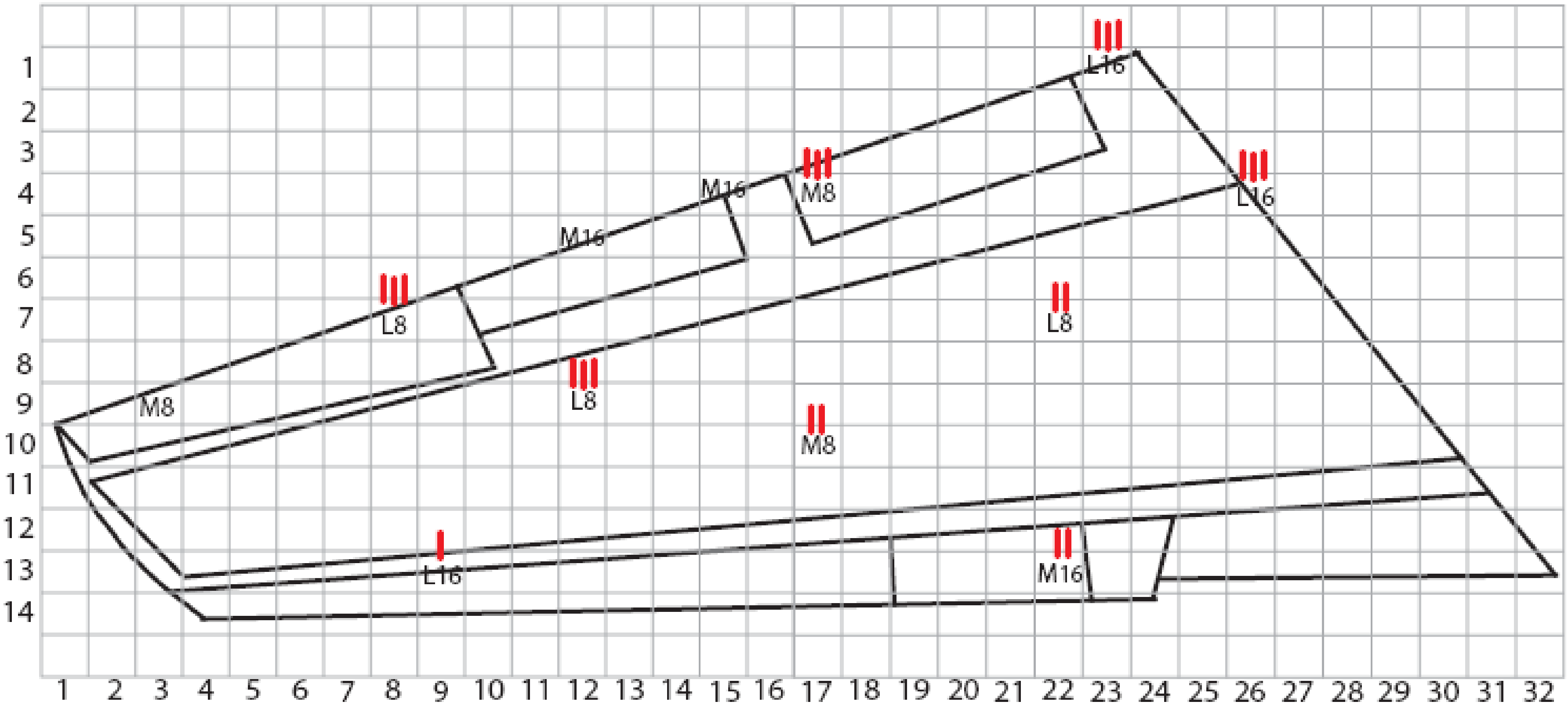
Leading Edge

GIDS 2

Test Diagram - Day 2
High Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



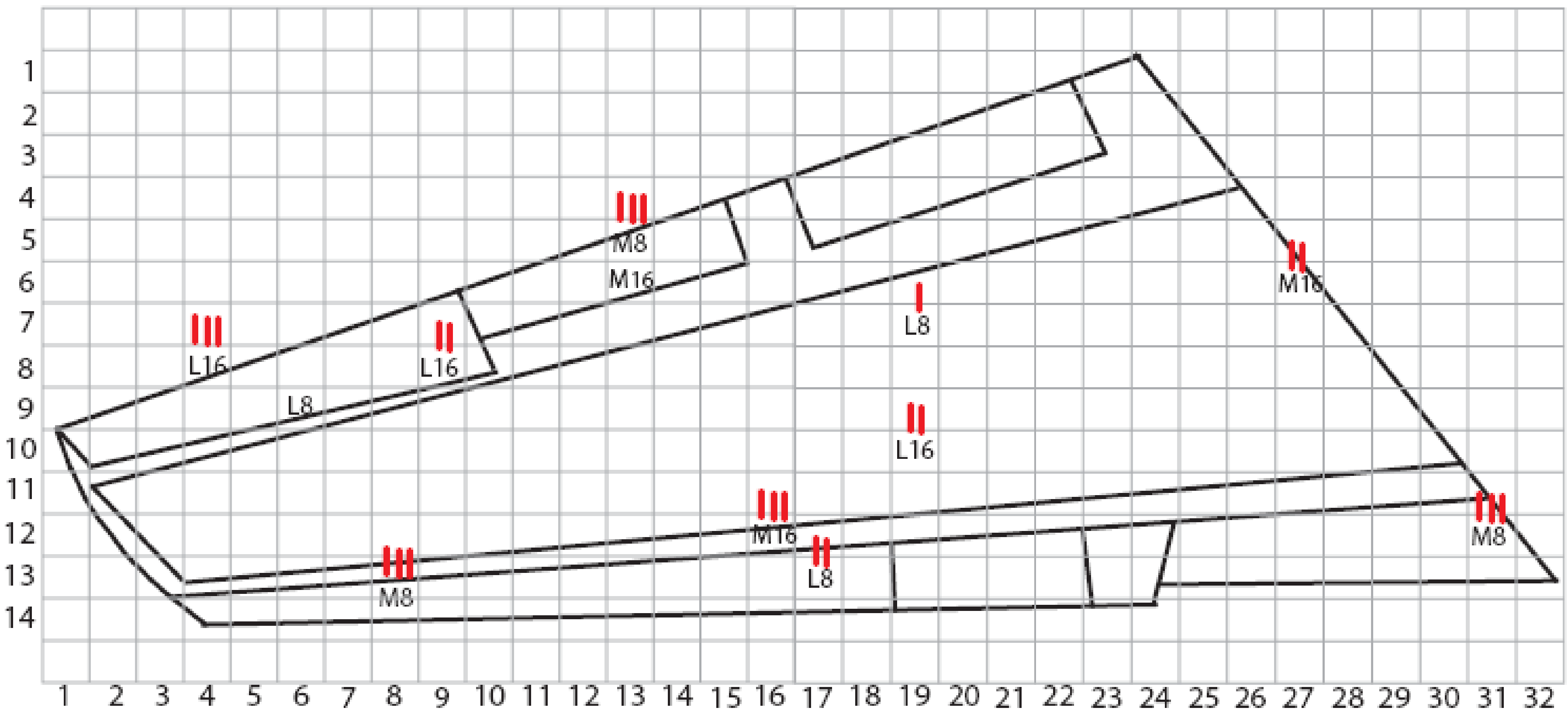
Leading Edge

GIDS 2

Test Diagram - Day 3
High Contamination Test

	L - Low (.3-.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)



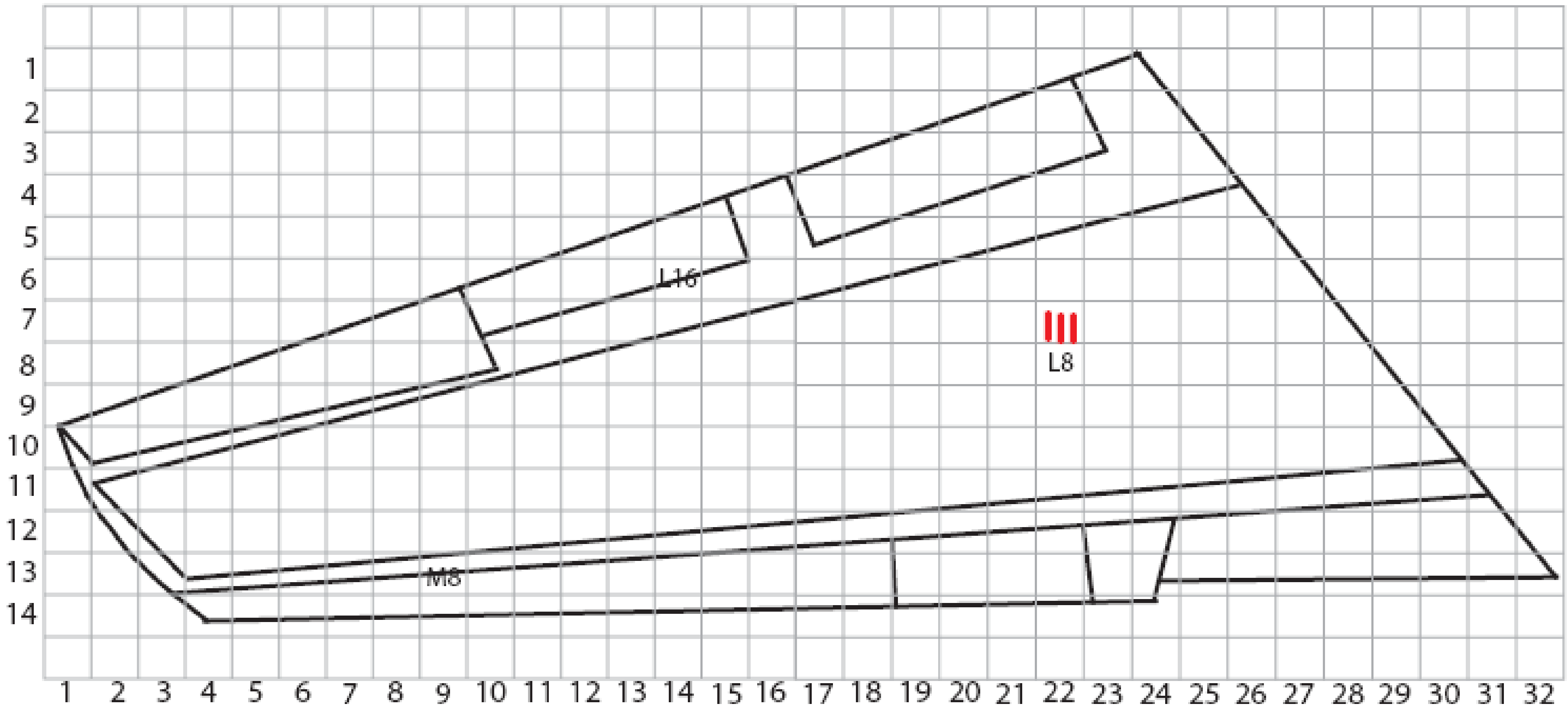
Leading Edge

GIDS 2

Test Diagram - Day 1
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16

| = Frequency Missed (maximum of 3)

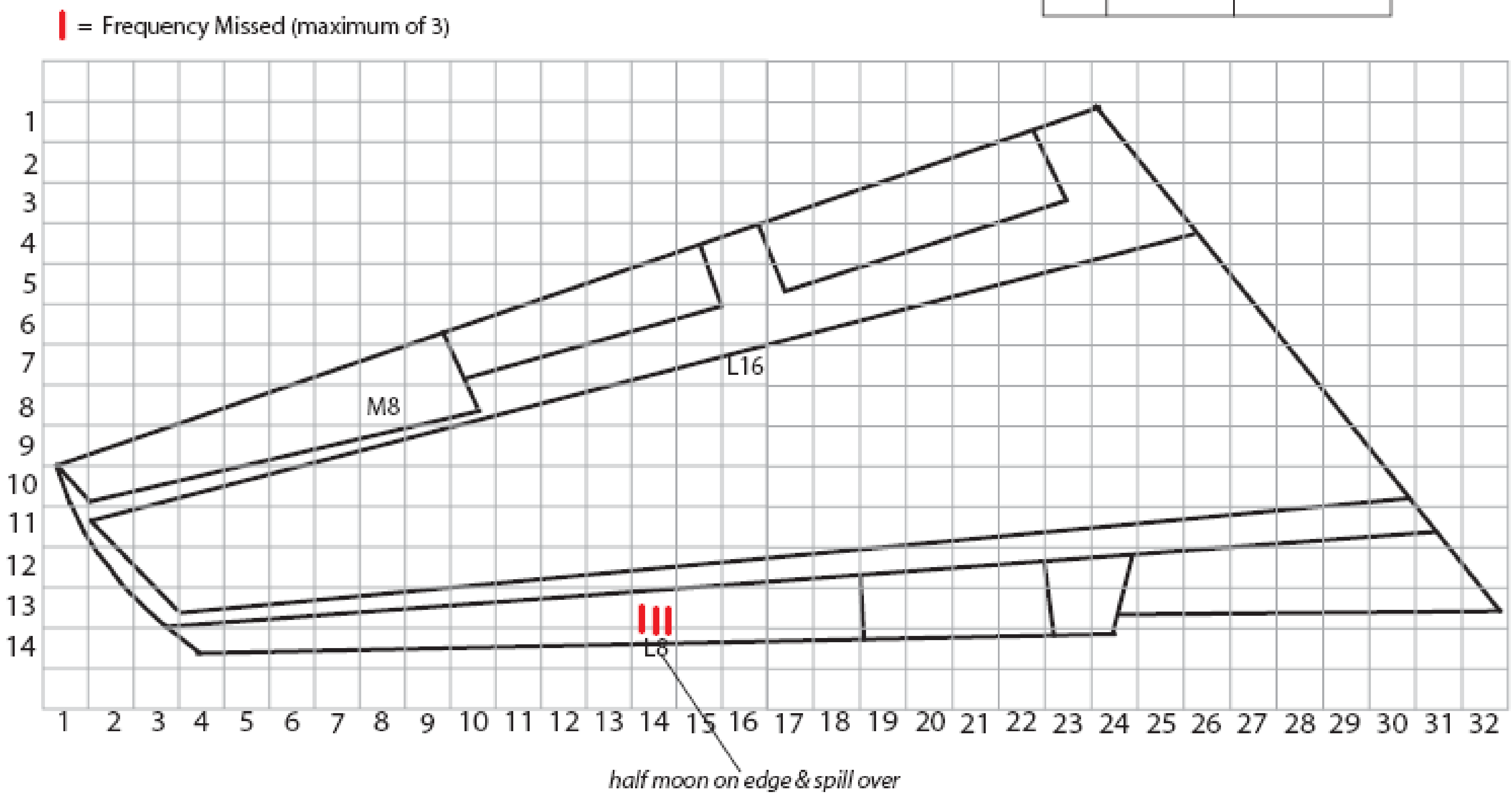


Leading Edge

GIDS 2

Test Diagram - Day 2
Low Contamination Test

	L - Low (.3 - .5 mm)	M - Moderate (.6 - .8 mm)
8in	L8	M8
16in	L16	M16



GIDS 2

Test Diagram - Day 3
Low Contamination Test

	L - Low (.3 -.5 mm)	M - Moderate (.6 -.8 mm)
8in	L8	M8
16in	L16	M16

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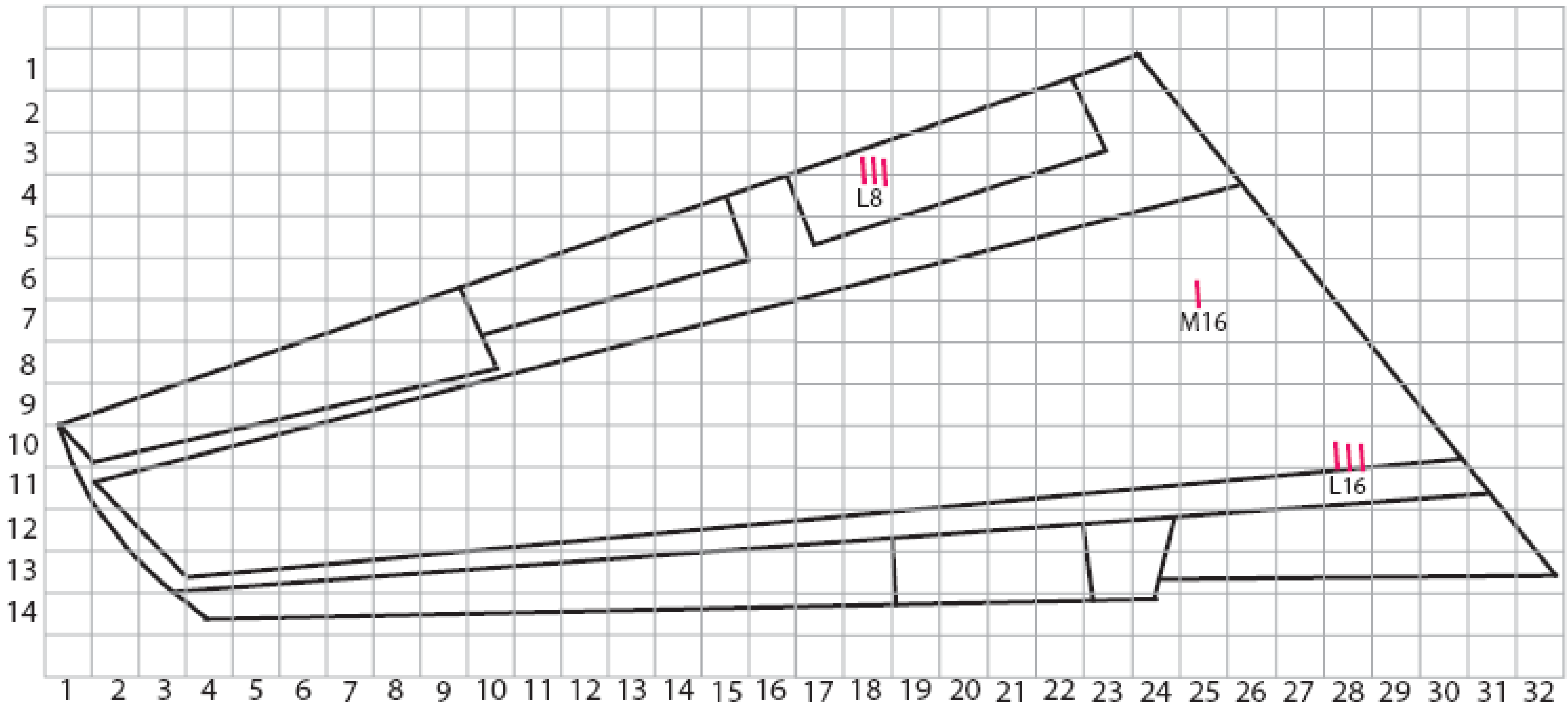

Leading Edge